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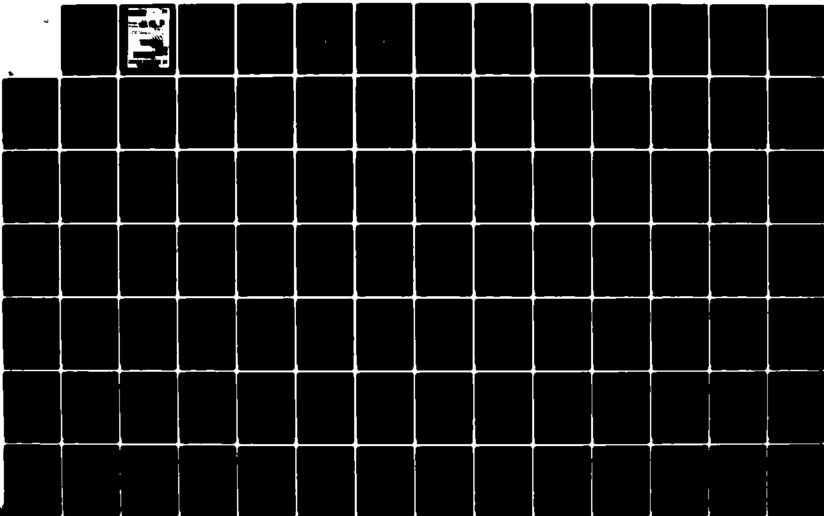

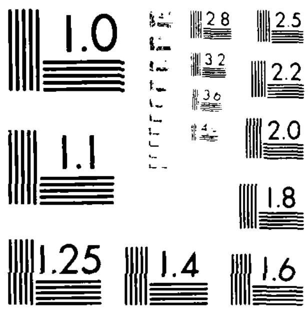

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Noise as a Public Health Problem

Proceedings of the Fourth International Congress

Volume 2

Editor

Giovanni Rossi, M.D.

EDIZIONI TECNICHE A CURA DEL CENTRO RICERCHE E STUDI AMPLIFON

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20. Abstract
The program for the conference was organized around the following eight working groups: 1) Noise-induced hearing loss, 2) noise and communication, 3) nonauditory physiological effects induced by noise, 4) influence of noise on performance and behavior, 5) noise-disturbed sleep, 6) community response to noise, 7) noise and animals, and 8) noise and other agents (physical and chemical). Each group provided a broad review of research in their respective area followed by invited papers on recent advances. At the end of each session either the chairman or a designated individual summerized the session and proposed directions for further study. Additional papers not falling under the above categories were presented in a separate session. Topics in this group included noise measurement, noise reduction, and expense of controlling noise.

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Giovanni Rossi, M.D.

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CONGRESS SUMMARY

Team No. 4

Influence of Noise on Performance and Behaviour

Chairman: E. Gulian (England)
CoChairman: S. Cohen (U.S.A.)

Invited Papers on Specific Topics

RECENT ADVANCES IN UNDERSTANDING PERFORMANCE IN NOISE.

Broadbent, D.E.

Department of Experimental Psychology, University of Oxford, England.

This five-year interval has brought a number of useful advances, and a review at this time can be more cheerful than was proper for those at the two earlier conferences. (Gulian 1973; Loeb 1980).

The plan of this paper will therefore be to state four areas in which there has been an advance, each with an illustration of one study that makes the point. We will then go into each area in detail, and finally point to some issues for the future.

THE AREAS OF DEVELOPMENT

(1) Arousal and the General State of the Person. As a key instance in this area, we may take the study of Loeb, Holding, and Baker (1982), in which they examined the speed of self-paced mental arithmetic in 95 dBA noise, either in the morning or in the afternoon. In male subjects, the speed of work was reduced in noise in the morning, and if anything increased in the afternoon. The importance of this finding is this. The time of day at which an experiment is performed is known to be related to the general state of the nervous system. Further, the discrepancy in the effects of noise at the two times cannot be due to alterations of task

difficulty, salience of one part of the task, actual details of the noise, and other factors which Loeb himself suspected in his review to be causing discrepancies between experiments.

(2) Discovery of Effects at More Moderate Intensities. The study by Loeb et al used a level of noise much higher than domestic or office levels, and indeed sufficiently high to be unacceptable by modern standards of hearing protection, for normal exposure throughout the working day. Until five or six years ago, the bulk of experiments showing detrimental effects on performance used equally high levels, and as a rough rule Broadbent (1979) suggested that a level of 95 dBA could be regarded as the point at which concern should be felt for possible effects of noise other than the transient effect of onset of a fresh sound. If so, most of the people who complain of noise in their offices and homes would have to be told that the noise was too faint to be impairing their efficiency. In the last few years however more sensitive tests have been devised, and it is now common to show effects at 85 or even 80 dBA. This greatly increases the practical importance of the topic; when office workers complain that they cannot write memoranda, or organise their time, in a noisy room we have to allow for the possibility that they may be right.

As the illustrative example, let us take a study not yet fully reported, by Jones (1983), for a reason that will appear. Jones made use of a serial reaction task very similar to one that loomed large in Loeb's review, because it has often shown effects at 95 dB or above. It had been tried at 90 and below without showing effects. Jones however used a silent keyboard with the person's fingers resting on the contacts rather than needing a large hand movement. Not only did he obtain the usual effect, but now the noise would impair the task even at the lower level of

90 dBC. Presumably the large hand movement of the original task meant that the person could correct some errors before the hand had reached the final part of its movement, and this method of minimising effects was removed in Jones' version.

(3) The Impairment of Language Function. The experiment by Jones used manual choice reaction, which is not a task closely related to language. That is the reason for choosing it as our example of the new generation of more sensitive tests; because a very large number of the new experiments use language, and it is fairly certain that some functions specifically connected with language are affected by noise. It is quite useful therefore to remember that there are sensitive tests that do not appear to involve language.

Once we have established that point, however, we can turn to the specific effects on language. Let us take, just as one example, a study by Wilding and Mohindra (1980). They studied memory for visually presented letters of the alphabet, and in some conditions they found that memory was better in noise of 85 dBC. Some aspects of the experiment suggested that the effect had something to do with the person's 'internal speech'. People who are trying to remember something often report saying it over and over internally. One can make this much harder by asking the person to say something irrelevant (such as 'the, the, the') all the time they are memorising. When Wilding and Mohindra did this, the advantage for memory in noise disappeared. Even if people were allowed to talk to themselves the advantage for noise only occurred when the letters were letters such as CDGTP, whose names sound very similar when one says them aloud. Letters such as HJRMZ, whose names sound different, did not show better memory in noise. Both these results argue very strongly that, although the experiment only involves visual letters and they are not

spoken aloud, the person is internally saying them and that this is somehow altered by the noise. At the time Wilding and Mohindra argued that the results looked like an increase in the tendency to use internal speech when noise is present; they have a more sophisticated theory now, and we shall come back to that. For the moment, let us take the study as showing specific effects on language.

(4) Dependence of Effects on the Strategy of the Person. At the last conference, Loeb's review emphasised the fact that effects will change if one changes small details of the task, the situation, or the subject population. These factors by themselves might be operating in a purely mechanical way, if for instance noise always increased the strength of the strongest reaction tendency or something of that sort. In recent years however the evidence has piled up that the effects depend on the strategy adopted by the person in doing the task, and can be altered without any change in the task itself. The notion of 'strategy' may need some explanation for non-psychologists; briefly, the same external task can in most cases be carried out by different internal operations within the person. Somebody remembering a list of words may say the words to themselves and try to reproduce the actual order in which they came; or they may group together words connected with the same topic, and forget about the order. A particularly clear case is provided by two studies by Smith and Broadbent (1982). They asked people to go through a list of words, each naming a class, and each accompanied by a single letter. The task was to produce a word belonging to the class and beginning with that letter. This task is easy if the letter allows one to respond with a familiar or dominant instance of the class; one can then simply run through instances of the class until one comes to a word with the correct initial letter. By suitable choice of a letter however the task can ex-

clude all words except an unlikely member of the class, and then this strategy becomes less helpful. Other methods will then be more appropriate, such as going through the alphabet for possible letters that might follow the presented letter, and checking to see if a possible word is suggested. Two groups of subjects drawn from the same population, given the same words and instructions by the same experimenter (and at the same time of day!), each showed a significant effect of noise on this task, but did so in opposite directions. One group did relatively better in noise on the dominant instances of a class, and relatively worse on the non-dominant instances. This is the familiar result of Eysenck (1975), which has been replicated on a number of occasions (von Wright and Vauras 1980; Millar 1979a). The second group of Smith and Broadbent (1982), however, did relatively better in noise on the <u>non</u>-dominant instances and worse on the dominant ones. The only differences we could see between the groups was that the first had previously taken part in an experiment in which they were asked to recall as many instances of a category as they could. That is, they had been practiced in the strategy of moving through a category from the dominant to the less dominant examples. Without that experience, the noise effect was in the opposite direction.

This experiment, like many others, shows that the effect of noise depends on the way the person is performing the task, the strategy. It is not a uniform mechanical change which always impairs the same task in the same way.

Let us now examine each of these areas of recent advance more closely.

AROUSAL AND THE GENERAL STATE OF THE PERSON

First, let us consider how noise effects vary with the general level of alertness or excitement of the person.

A number of previous investigators have of course suggested that

noise has its impact through changing the level of arousal, and that there fore the noise will be harmful or helpful depending on the other factors that are affecting arousal. The oldest idea is that a certain amount of arousal is helpful, but that beyond a crucial level depending on the task arousal can be excessive. Thus the notion was that bad effects of noise might be cancelled out by factors that reduce arousal and increased by factors that increase it. This kind of view has been supported by other studies in recent years; Hartley et al (1977) have found partial cancellation of effects of noise by chlorpromazine, though with some complications. Colquhoun and Edwards (1975) found similar cancellation with alcohol. In the opposite direction, von Wright and Vauras (1980) have in several experiments found that detrimental effects of noise are greater in individuals who are higher on a questionnaire measure of neuroticism. The same finding is independently reported by Dornic (1980), though in the latter case the differences in performance could in some cases be masked by differences in compensating effort exerted by the person.

If then one accepts that people with high neuroticism scores show larger effects, it becomes very relevant that in two studies (Standing and Stace 1980; Edsell 1976) it has been found that people exposed to noise show a rise in a measure of 'state' anxiety, that is, of anxiety felt at the moment rather than as a general rule. Investigators who believe in a single dimension of arousal, with an optimal level, could therefore argue that the neurotic people have a chronically high level of arousal, that noise increases this further, and that therefore such people are especially vulnerable to bad effects of noise.

Unfortunately, this simple view is wrong. A number of doubts about it were expressed more than a decade ago (Broadbent 1971), and the study by Loeb and colleagues (1982) makes them even more clear. Remember,

noise was more harmful in the morning than the afternoon; so to use the simple theory one would have to argue that arousal was higher in the morning. But, it is well established that certain indicators of arousal, such as body temperature, are higher in the afternoon rather than the morning. Further, a large array of tasks are better performed in the afternoon than in the morning, their performance following the change in body temperature. (Colquhoun 1971). Psychologists working on the effects of time of day have therefore tended to argue that there is a peak of arousal in the late afternoon, not in the morning. So, a theory postulating one dimension of arousal can explain the results from experiments on time of day (by supposing highest arousal in the afternoon) or the results of Loeb et al on noise (by supposing highest arousal in the morning); but not both.

There are still further difficulties for the simple idea. Loeb et al (1982) found that adding women to their analysis eliminated the clear result found with men; and in another study with a rather different task they found that women give a reversed relationship. (Baker, Holding and Loeb, in press). It is very difficult to see how one could explain a decrement with noise in the morning for one sex and in the afternoon for the other, with a single concept of arousal.

If one turns for guidance to the psychologists investigating circadian rhythm, one finds that they also have complicated their approach in recent years. Studies of people living on abnormal schedules have been able to distinguish some physiological variables that follow the cycle of sleep and wakefulness, and others that follow an endogenous rhythm with a period of roughly one day. There seems to be some evidence that certain psychological tests follow one of the rhythms and some follow the other. (Folkard and Monk 1980, 1982). In this field also the most likely work-

ing hypothesis is that there are two mechanisms whose level of activity or arousal can go up or down, not one. A similar conclusion comes from studies of self-reported mood, using adjective check-lists (Mackay et al 1978). Some people are excited or alert, others tense or worried. Some people may be relaxed or calm, others sluggish or depressed. There are two kinds of relatively high excitation and two kinds of low excitation.

Returning to experiments specifically on noise, we find that studies comparing and combining noise and other stresses often fail to confirm the idea of a single dimension of arousal. Bell (1978) found that effects of 95 dBA noise were similar whatever the level of environmental temperature. Finkelman et al (1979) found that 90dB noise increased errors, but the effect of noise was the same at different levels of physical exertion. Yet the exertion increased heart rate, one plausible measure of arousal; the noise, incidentally, did not affect the heart rate. A third recent paper (Fowler and Wilding 1979) showed partial overlap between the effects of noise and of financial incentive, but partial independence. The conclusions we have to draw from all these studies are, first, that the effects of noise do depend upon the general state of the person. Second, it is too simple to hold the notion of a single dimension of arousal which has an optimum point at which performance will be best for a particular task. The response of Broadbent (1971) to such difficulties was to argue that there are at least two mechanisms involved; one corresponding to the now traditional concept of arousal, and one to a monitoring or controlling system that attempts to compensate for departure of arousal from the optimum level. If the second system is in good shape, the first does not affect performance much; when the second system is in bad condition, performance is badly affected by over-high or over-low arousal. In 1971, the best guess was that noise, sleeplessness, amphetamine, chlorpromazine,

affect one of these systems while time of day, alcohol, barbiturates, and the personality dimension of introversion affect the other. The experimental work of the last decade is still consistent with this classification, although one would probably wish to add caffeine to the factors in the second list because of its interactions with introversion and time of day (Revelle et al 1980). Frankly, this theory has not been seriously tested and is almost certainly wrong in detail. The main point is that a theory of at least this degree of complexity is required.

IMPROVED SENSITIVITY OF TESTS

Given that one effect of noise is to change the general state of the person, we then have to ask what changes to recent tests of performance have made them more sensitive, so that effects are now being found at lower noise levels. As we have seen, Jones (1983) seems to have made his task more sensitive by reducing the amount of spare time available to the decision mechanisms; more typically, the sensitive tasks are ones that ask the person to do two things at once, or in which there are two aspects to the task that carry different weights. Often they involve memory, and frequently some aspect of language. The most common effect is that one measure of performance deteriorates in noise and another improves, or at least is unaffected. Amongst studies we have already considered, for example, Bell (1978), von Wright and Vauras (1981) and Fowler and Wilding (1979) used dual measures. Loeb (1980) quoted a number of such tests showing effects at higher levels, and Cohen and Lezak (1977) provide a further example.

As examples of the reality of effects well below 95dBA, let us take two areas; that of vigilance and that of semantic clustering in memory. Vigilance is the detection of occasional signals in a monitoring situation; the consensus of past years was that it was unaffected or improved in

moderate levels of noise. But earlier studies used detection of changes in intensity of some standard visual signal, or comparable straightforward and almost psychophysical situations. It is also possible, and equally comparable to real life tasks, to ask the person to search for some signal that is always changing, so that there is a strong memory component and possibly a verbal component as well. For instance, the task might be to watch a series of single digits, and to report any sequence of three digits that are odd-even-odd. Thus in one context one digit may represent a signal and in a different context a different digit. With tasks of this kind, deterioration can be found at 85 dB or even lower (Benignus et al 1975; Jones, Smith and Broadbent 1979; Klotzbucher and Fichtel 1979).

A more direct memory experiment is to present a series of words for recall. Although presented in random order, they may be words drawn from a small number of semantic categories; and if so, there is a tendency for people to remember them grouped or clustered by those categories, rather than in the actual order of arrival. This tendency is sometimes reduced in noise of 85 dB or even less (Daee and Wilding 1977; Smith, Jones and Broadbent 1981). The total number of words recalled, on the other hand, may be no fewer than it is in quiet.

A memory task involving two measures is to present a series of words and to ask later for recall of their order, or of the spatial location where they appeared. Usually, order recall improves in noise and memory for place gets worse. (Daee and Wilding 1977; Smith 1982). This is not a constant effect of noise improving order however; Niemi, von Wright, and Kowunen (1977) had difficulty replicating the effect, and Smith (1983) showed that order of recall only improved in noise early in an experimental session. Later, it deteriorated. The key point is that both Smith

(1982) and Daee and Wilding (1977) got the effect only when people were instructed to give priority to remembering order; if place had priority, there was no improvement in noise for order. The main task tends to improve and the minor one to deteriorate. Thus, certain tests do seem to be especially sensitive to moderate levels of noise, and on the whole they are tests with primary and secondary parts, where the primary involves memory for order, and the secondary is less obvious or more subtle. In such a test, there is a good chance that the secondary task will deteriorate in noise even at only 80 or 85 dBA.

EFFECTS SPECIFIC TO LANGUAGE

This is the point to take up the special effects of noise on language functions, which have been increasingly understood over the past five years. There are two groups of effects that are worth considering separately. The origins of this interest are described by Loeb (1980); since then, progress has been rapid.

(a) Effects of Irrelevant Speech Sounds. Anybody who has glanced through the literature of cognitive psychology will be familiar with the Stroop test. The original effect was that a person trying to name the colour of the ink in which a word is printed is very much disturbed if the word itself is the name of a colour. In recent years however similar effects have been shown in tasks other than colour naming (e.g., Eriksen and Eriksen 1974) and even when one stimulus is visual and the other auditory (Navon 1977). One can generalise by saying that a person trying to choose between two actions or percepts is likely to find it more difficult when some irrelevant stimulus arrives that is associated with the wrong action or percept. For instance, if you watch a screen and try to press an appropriate reaction key when an A or a B appears on the screen, then your reaction to an A will be slowed down by the appearance

of a B in the wrong part of the screen. A letter which is not A or B will have little effect, and this is perhaps why the possible impact of the phenomenon in the case of noise has escaped notice. The noise stimulus used in experiments is often appropriate to none of the actions in the tasks being used as tests; but speech sounds are natural and practiced stimuli for words, and words are frequently used in psychological tests. In fact it has been known at least since the work of Rochford and Williams (1962) that the task of naming a picture will be disturbed by hearing the wrong name at the moment the picture is displayed. When speech sounds are used as the 'noise' in experiments, and words are involved in the task, the effects are more serious than when meaningless noises are employed (Salame and Baddeley 1982). It is even true that speech sounds in another language have an effect (Colle and Welsh 1976; Colle 1980). From a practical point of view, this is probably the most important change of emphasis in recent years. In the past we have neglected the point that a person who is trying to read a letter or compose notes on a conversation may suffer interference when colleagues talk nearby, and particularly when they talk about the same topic.

(b) Effects on Memory Rather than Perception. The next question is whether there are effects on internal speech other than the Stroop-like effect. Are there effects on memory for words seen before the noise occurred, and perhaps effects of meaningless, rather than speech-like, noise? It is worth emphasising that Salame and Baddeley (1982) themselves regard their experiment as showing an effect on memory and not merely on perception. Their view is that when one reads a word one says it to oneself, that this converts it into a kind of acoustic image, and that the noise makes this image hard to discriminate. They point out, for example, that making people articulate irrelevant material, and thus suppressing

internal speech for the memory material, reduces the effect of the noise. My personal view is that their effect, important though it is, does not represent an effect on memory but only on perception. I would produce three reasons for this alternative view. First, articulatory suppression is known to reduce the ordinary Stroop effect when no memory is involved (Martin 1978); so using it to reduce the noise effect does not provide positive evidence that the effect is in memory. Secondly, it is already known that presenting speech sounds after visual material has been read does *not* disrupt memory (e.g., Martin and Jones 1979). It *does* disrupt memory for words that have been heard rather than seen, and this is usually taken as evidence for some special memory for sounds or for speech (see a number of papers in Broadbent 1983). If internal speech transferred visual words into such a store, later irrelevant speech ought to disrupt it; but the Salame and Baddeley effect depends on the noise being present during visual perception, not afterwards. Hence, I see it as a Stroop effect in perception, not a masking of internal memory.

My third reason for holding a different theory of this effect is that there are undoubtedly other effects on internal speech used as a memory system; these have been shown chiefly by Wilding and Mohindra, and are quite difficult to reconcile with the notion that noise masks an acoustic image. Recall the results of Wilding and Mohindra (1980) quoted earlier; noise improves memory, but only if internal speech is allowed and only for letters that are rather similar rather than those that are different. This must be an effect on internal speech, but it cannot be a simple equivalent of masking. Similarly, Millar (1979b) studied memory for lists of consonants, with and without articulatory suppression. If noise masked internal speech one would expect a harmful effect on memory, but less so when articulation was suppressed. Millar found no such result

overall, but did find improvements in order recall when articulation was suppressed.

Mohindra and Wilding (1983) have made an important attempt to formulate what the explanation may be. They start from the fact, which they have established, that people asked to articulate items aloud do so more slowly in noise. It is already known that the number of items that can be held in short-term memory by the internal speech mechanism depends on the time taken to say the items (again, see Broadbent 1983). Slower articulation implies that fewer items will be available in short-term memory; but in addition to the number of items one must also consider the problem of recalling them in the correct order. When a person tries to recall, the problem of picking the next item depends partly on the number of other items in memory and partly on the degree of confusion between the correct item and each of the others. If items are very confusable with each other, for example if they are CGDTP, the chance of an order error will increase very steeply as the number of items in memory increases. In that case, the person may paradoxically make so many mistakes when he has a lot of items in memory that the total score will be better if he has only a few items in memory. Therefore, with confusable items a measure of recall in correct order will be highest if the person is articulating slowly; say, in noise. If the items are easy to discriminate, for example if they are HLMRZ, confusion between items becomes less important as a source of order errors, and the slowness of articulation will be reflected in worse memory.

This theory has the great merit of making it easy to remember the rather complicated pattern of results; because the prediction stated is just what Mohindra and Wilding find. My personal view is that I wish to remain agnostic about the ultimate acceptability of the theory because I

am worried about some of the assumptions. For example, it makes a strong prediction that ordered recall will, for confusable items, be less when there are more items in memory. This ought to be verifiable in experiments not using noise at all, and I am not clear that it has been reliably shown.

In summary however there are certainly results on memory in noise that implicate internal speech, and that are often improvements rather than deteriorations. Experiments with non-confusable items, with speech-like noise, and especially with noise at the time of reading, will give deterioration with quite low levels of noise.

THE CHOICE OF STRATEGIES

In all the results we have reviewed, a recurrent theme has been that the effects of noise cannot be seen as a passive and mechanical change, which always and invariably makes order memory better, or impairs tasks requiring deep semantic processing. Some effects are very common, but none are invariable. The same point is made by the last of our four keynote experiments, that of Smith and Broadbent (1982).

It was reported by Hamilton, Hockey and Rejman (1977) that noise would give changes in 'running memory'. That task requires one to listen to a stream of items that is stopped unexpectedly; whereupon one has to recall the last eight items. Noise of 85 dB deteriorates recall of the most remote items, but on the whole improves recall of the last one or two. Smith (in press) has however tried the task not only in the original form but with the instruction to recall only the last five, not the last eight. When this is done, the noise tends rather to impair the last items presented and to leave the earliest ones unscathed. If you analyse more closely what is happening, you find people who know they only have to recall five items go back into the past as soon as the sequence stops;

they begin recall at or about the fifth item back. When they are asked to recall eight, however, they start by reproducing the very last items, of which they can be reasonably sure. Then they go back and do what they can about the harder ones. The noise appears to strengthen the tendency that people have in each of these situations, so that the part of the memory that suffers is the one that, in the absence of noise, would be given the lowest priority. One is not studying the rate of decay of a passive memory trace, but the choice of a strategy of recall.

Another example is provided by the experiments on reduced semantic clustering in noise, which have already been mentioned briefly. (Smith, Jones and Broadbent, 1981). In general, words are clustered less by meaning when noise is present. But this effect does not appear when the meaning groups are obvious or impossible to see. To get the effect on clustering, it is necessary for the person to have a real choice of methods of performing the memory task. Then, the noise gives a shift between the methods.

Suppose one suggests that noise alters the mechanism used for selecting strategies. Then suppose that the mechanism becomes more extreme in its working in noise, so that the strategy more likely to be adopted in quiet becomes almost certain to be so in noise. That would account for the frequent finding that the secondary parts of tasks are more likely to be impaired in noise; and that common strategies, such as the use of internal speech for memory tasks, appear to be applied even more frequently.

Even this attractive generalisation runs into difficulties however, in certain findings of Dornic and Fernaeus (1981) and of Smith and Broadbent (1981). The first of these required people to alternate rapidly between two tasks; this made performance worse at both types of pro-

cessing, and especially so in noise. One cannot explain this by a shift of priority towards one kind of task. It looks much more as if, once a mode of performance has been selected, noise makes it harder to change. Smith and Broadbent (1981) have a related finding; in two of their experiments the subjects meeting noise as their first condition continued to behave differently throughout the experiment, even in quiet. If noise affects the selection of strategy, it is most likely to be through making the strategy more difficult to change once adopted.

A last study makes the same point. Smith (in preparation) has tried a serial reaction task with lights and touch contacts, as did Jones (198[illegible]); in Smith's case however he made the signals unequally frequent. The probable stimulus gave faster reactions in 85 dB noise, and the rare stimuli slower ones. But even when the relative probability of signals was returned to normal, *the signal that was formerly more frequent continued* to show relatively better performance in noise. The mode of performance had apparently become fixed. This kind of effect may well explain the very frequent occurrence of carry-over effects of noise, which Loeb's review again has emphasised.

Smith's experiment again does not involve language. It resembles many of the studies using linguistic material in the pattern of results, but in this case the findings cannot be put down to an effect specific to internal speech. From the point of view of an enthusiast for strategic changes, the reason for the appearance of linguistic material in so many sensitive tests is that verbal processing can normally allow many different strategies, not because the effect of noise is something specific to speech.

CONCLUSIONS

It was said at the start of this paper that the tone can fairly be

more positive than was proper for the previous two reviews at these congresses. Let us summarise the achievements of the last five years.

(1) We now have tests that are sensitive to levels of noise much more comparable to office and domestic levels.

(2) One such test employs the Stroop-like effect of speech sounds on verbal tasks even when the task involves reading rather than listening.

(3) There are also effects related to internal speech, that are clearly complex and go broader than a simple masking theory, but are in sight of being understood.

(4) We also know that changes in noise effects can be found, not merely with slight changes in task, but even on identical tasks when they are approached in different ways. This applies to non-verbal as well as to verbal tasks. Thus, it is plausible that the effect of noise has to do with the selection of a strategy of performance by the person.

(5) Lastly, we know more certainly than before that the impairments due to noise are related to some general arousal-like change of state in the person, and that a single dimension of arousal will not do. The use of natural changes in the person during the day is a particularly good way of attacking this problem.

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PHYSICAL NOISE VS. SEMANTIC NOISE: THE EFFECT ON INFORMATION PROCESSING.

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INTRODUCTION

Auditory pollution belongs to the most common environmental stressors, both by itself and when combined with other stresses. Of special importance is its combination with high information load that occurs in a number of occupations. Information processing, even if far from stress level by itself, may turn into overload when combined with auditory environmental stress — with serious consequences for performance as well as for the cost of performance i.e. effort.

Auditory environmental stress is typically associated with intensity, although annoyance is attributed to noise's other dimensions as well, but to a much less degree. It is true that noise intensity, if very high, means an immediate threat to human organism. However, when noise, i.e. auditory stimulation irrelevant to the task a person performs, is present simultaneously with that task, the content of noise may become much more destructive than intensity, and through

its interrupting and frustrating power, it may even present a serious threat to the performer's wellbeing and health.

As inspection of the literature on noise effects on information processing will reveal, the concept of noise covers a great number of very different types of auditory stimulation: continuous and intermittent, meaningful or meaningless, random or predictable, aversive or sedative noises may produce some common and some very different effects. Even relatively small changes in noise intensity can yield unexpected nonmonotonic effects (e.g. Daee & Wilding, 1977); the same applies to noise duration (e.g. Hartley, 1973; Smith, 1983). Direct and indirect effects of noise tend sometimes also to be confounded. This diversity, together with task specificity which has been repeatedly made responsible for contradictory data obtained in seemingly identical experiments (e.g. Jones & Broadbent, 1979; Poulton, 1979; Smith & Broadbent, 1982; Smith, Jones & Broadbent, 1981), may explain why only modest generalizations can legitimately be made in this research area.

As a simple, easily definable, general representative of auditory stress, white noise has served for several decades as an excellent tool for studying a great number of information processing mechanisms. An increasing number of investigators appear to feel, however, that it is time for the studies of noise to "move away from their previous preoccupation with white noise of varying intensity, and... ...instead systematically investigate the disrupting effect of more pat-

terned sources of noise, paying particular attention to the disrupting effect of unattended speech" (Salamé & Baddeley, 1982). Recently, these and other authors have started a series of studies concerned with memory and other cognitive processes. The data obtained up to now support the assumption that disruption of various information processing mechanisms is frequently due to noise's content rather than intensity. The present paper is concerned with one of important dimensions of noise, viz. meaningfulness. Throughout this paper, meaningful, verbal noise will be called "semantic" while meaningless, nonverbal noise will be labelled "physical".

In an earlier study (Dornic, Sarnecki, Larsson & Svensson, 1974) we used short tasks with relatively high information load (involving reasoning, interference, limited long-term memory search, attention switching, and load on working memory) that the subjects performed in quiet, in high intensity physical noise, and in low-intensity semantic noise (distracting speech). In the short tasks whose duration varied between 1 and 4 min the subjects generally managed to overcome noise effect by increasing effort expenditure, so that only negligible decrease in performance could be observed. Perceived difficulty of the task was, however, higher in the noise conditions than in quiet, much more so in semantic noise than in physical noise.

The present study concentrated on the time variable. Compensatory mechanisms found in the above study are likely to be sensitive to task duration; the same applies to pos-

sible adaptation mechanisms. It was hypothesized that task duration would differentially affect the influence of the two types of noise — physical and semantic, respectively — on the efficiency with which the task is performed.

An obvious crucial variable in this sort of experiment is the task. Although the determinants of a task's sensitivity to noise are not easily explained, it appears clear that the task should be difficult enough, in terms of the complexity and speed of operations it requires, or in terms of effort it requires and the spare capacity it leaves unused (cf. Dornic, 1980a; Dornic & Andersson, 1980).

This paper reports one of several experiments carried out in our laboratories using different types of high-load tasks (e.g. Dornic, 1981; Dornic, Sarnelid, Larsson, Svensson & Fernaeus, 1982) to study the effects of various types of noise. This report gives a selective comparison of two types of noise which can be considered opposite extremes at two continua: that of meaningfulness, and that of intensity. The effect of high-intensity, meaningless white noise is compared here against that of meaningful, verbal noise of low intensity.

With physical noise, intensity is generally considered essential for most, if not all, of its effects such as arousal, distraction or masking, although the increase in these effects with intensity need not be monotonic (e.g. Dace & Wilding, 1977). Semantic noise, on the other hand, shows little, if any, interaction with intensity except at very high intensity levels where the increase in disrupting power

of semantic noise is due to its physical aspects rather than its content: within a reasonable range of intensities, the disrupting power of semantic noise does not seem to depend on intensity (cf. Colle, 1980; Dornic, 1981).

METHOD

Noise and task. The physical noise was a white noise played back by a loudspeaker located about 1.5 m behind the subjects; its intensity at the subjects' ears varied around 85 dB. When applied, the noise was turned on half a minute before the subject started working on the task. Intensity was increased gradually, within 15 sec, to the 85 dB level. The semantic noise was a tape-recorded conversation between two mail voices on simple everyday topics. The noise was reproduced at about 65 dB, the intensity being appropriate with regard to the experimental room's background noise level.

The task involved simultaneous mental operations such as language encoding based on limited long-term memory search, rehearsal load, and processing of digital information. The subjects' task was to name colors of a series of patches, at the same time transforming two digits, following every third color patch, by adding one to each of the two digits; for instance, numbers 2,5 were to be processed to 3,6, then 4,7, and so forth (9 was followed by 0 so that the subject was always dealing with two one-digit numbers). The task difficulty was enhanced by digits and words, irrelevant to the task, printed outside the regular location of the patches but within the subject's reading field; the interference words belonged to the category of color names.

Subjects, design and procedure. Thirty subjects participated in the experiment, 15 males and 15 females, drawn from high-school students and university undergraduates studying a variety of disciplines. Their ages ranged between 17 and 29 years (mean 24.9). All had acted earlier as subjects in experiments on attention, and most of them had had previous experiments with simple scaling methods used here. The subjects were randomly assigned to three groups of ten persons each. In a between-subject design, each group (N=10) took part only in one of the three conditions: Quiet, Physical Noise, or Semantic Noise.

The task's overall duration was 15 min, divided in four periods of 3 min 35 sec. During the short pause of 10 sec following each period the subjects gave their estimates of effort they had to expend to cope with the task. This was done on a graphical scale, numerically and verbally anchored at the end points (0 = "no effort at all", 10 = "extreme effort"). The estimates were always concerned only with the immediately foregoing task period.

RESULTS AND DISCUSSION

Table 1 shows mean performance and perceived effort for the two tasks in the three conditions. For reasons of space, only statistical comparisons which make sense in the present context, are given here. Since our major problem is task duration, the comparisons will concern task periods 1 and 4.

Table 1. Performance (P) and perceived effort (E) in the four task periods of the three conditions. Performance is expressed in number of correctly processed items per min.

	Task periods							
	1		2		3		4	
	P	E	P	E	P	E	P	E
Quiet	53	4.0	51	4.2	51	4.8	51	5.1
Physical noise	50	5.1	48	5.5	49	5.2	5[illegible]	5.0
Semantic noise	49	6.9	46	7.1	44	7.9	39	9.0

Performance in Quiet remains virtually unchanged throughout the four periods while there is a slight but nonsignificant increase in self-reported effort expenditure. Performance in Physical noise initially decreases but finally improves; this trend is reflected by slight changes in perceived effort. The difference in performance between task periods 1 and 4 in Physical noise closely approaches the .05 significance level. Performance in Semantic noise displays a steady downward trend, the opposite being true of perceived effort. The difference between Periods 1 and 4 is highly significant for performance ($p < .001$) and significant for effort estimates ($p < .05$).

A comparison of the three conditions at the shortest duration (Period 1) indicates a slight, nonsignificant trend for performance to decrease from quiet to Physical noise to Semantic noise. In terms of effort, this trend is more pronounced: the Semantic noise condition differs significantly from Quiet ($p = .05$). With prolonged task duration (Period 4), there is a marked change: performance in Physical noise is slightly, though not significantly, better than in Quiet, but performance in Semantic noise is clearly inferior to both the other conditions ($p < .001$); the same applies, in a reversed sense, to effort ($p < .01$). The difference would be still more pronounced if expressed in terms of efficiency i.e. performance-to-effort ratio (Eason, 1963; Dornic, 1980b).

The overall picture appears to justify the conclusion that low intensity semantic noise, while by itself much less annoying and harmful than physical noise, may prove much more detrimental when combined with mental work. As mentioned above, very similar data have been obtained in experiments using other types of high-load tasks (Dornic, 1981; Dornic et al., 1982). What are the basic differences between the two noise types?

The basic difference apparently lies in a very different "interrupting power" of the two noises compared. The distracting, disturbing effect of noise can of course come from various sources — which can be both physical and semantic in character. However, even if a physical, meaningless noise is patterned, intermittent, or variable in any

other way, it is always more predictable than semantic noise.

The disruptive effect of the semantic content of noise on information processing is of course task-specific. To illustrate and underline the importance of task, a recent study by Salamé and Baddeley (1982) will be mentioned here. Performing what could be called a microanalysis of an extremely simple short-term memory task, they found that semantic characteristics of "unattended speech" (isolated, unrelated words presented auditorily) did not affect retention of visually presented digits: nonsense syllables had about the same effect. Their conclusion that "the effect is not operating at a semantic level" and that "the system is not sensitive to meaning" cannot of course be generalized beyond that particular task.

The position of the present author is that the role of the semantic content of noise in the task used in the present experiment primarily lies in the interruption of continuous, coherent information processing. The nonsemantic features of speech that the subject is instructed to consider as noise lack that power. In one of our earlier studies (Dornic, 1981), the influence of nonsense syllables, and continuous speech in a foreign language totally unknown to the subjects (conditions that involved the same broad phonological characteristics as the words in the subjects' own language) had by far not so marked disrupting effect on a continuous visual information processing task as unattended speech in their own language used in another condition. Thus, while physical

characteristics of semantic noise, such as phonological sim-ilarity to the task, may be decisive on a micro-level, they probably lack significance in more complex tasks. The same applies to the finding by the above authors that general attention distraction could not explain irrelevant speech effects in their experiments: distraction, while unimportant in a discrete, simple short-term memory task, is certainly much more relevant in a complex, continuous task. In such a task, much more processing capacity must be used to reject semantic noise than physical noise (cf. Dornic, 1977, 1980b; Eysenck, 1979).

Another of noise's often discussed effects is arousal. It may be reasonable to assume that in spite of low physical intensity, semantic noise increases arousal via continuous interference with the task, and through the resulting frustration: an obvious effect that has come to be discussed recently under the name of "interruption", as a source of emotions (e.g. Mandler, 1975). While with physical noise, arousal typically increases at the onset of noise and then decreases (e.g. Poulton, 1979) displaying a typical adaptation effect, the level of arousal induced by semantic noise is less likely to decrease since little, if any, adaptation can be expected to take place.

Out of the several effects frequently attributed to arousal, it seems appropriate to mention decreased semantic processing under arousal, first reported by Schwartz (e.g. 1974) that — together with the assumption of high arousal

directing attention towards dominant sources (in the present case, towards the task rather than noise) — should favor the prediction of noise attenuating the disturbing effect of semantic noise relative to the physical one. Such a prediction would be quite difficult to test; in any case, if arousal attenuates the effectivity of irrelevant semantic stimulation, this effect is probably much less robust than that of interruption.

Finally, the controversial masking effect of noise should also be mentioned. Following the several years lasting argument about the role of masking by noise, the possibility of this effect has come to be considered again (e.g. Colle, 1980; Salamé & Baddeley, 1982). If some sort of masking is to be considered in the present context, one should emphasize the fact that masking of overt or covert verbal operations does not necessarily depend on the masking agent's intensity but rather on its phonological similarity with the task.

The major finding in the present study was the differential effect of the two types of noise with respect to the task duration. That physical noise can improve performance, has been sufficiently documented (Poulton, 1976) although this may result in a decrease of processing capacity that will sometimes show up in an inferior performance on another, simultaneously performed task (Broadbent, 1977). The mobilizing effect of irrelevant stimulation has been demonstrated even with distraction other than noise (e.g. Sanders & Baron, 1975).

The results always depend on the concrete combination of a particular task with a particular noise. In many cases, as in the present one, it appears worthwhile to use some sort of effort measurement that indicate compensation mechanisms pointing out to a decreased processing capacity, at an earlier stage than performance measures do. Evidence is accumulating that perceived effort, as measured by simple psychophysical scales, can serve as an integrative measure, in several ways superior to seemingly more exact, but also more indirect, behavioral and physiological measures (e.g. Borg, 1982).

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DIFFERENTIAL EFFECTS OF NOISE AND SPEECH ON SHORT-TERM MEMORY.

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INTRODUCTION

Many investigations have been concerned with the effects of noise on human performance and in particular have focussed on short term memory. Theylead however to conflicting and even controversial results (Poulton, 1977 ; Broadbent, 1978 ; Poulton, 1978a, 1978b). The various memory tasks and experimental paradigms, when combined with the large number of noise variables manipulated in these studies, could explain the quite discrepant results obtained. Other explanations are still possible however.

Rather scarce were studies of the effects of speech as an acoustic environment on memory (Colle, 1980 ; Colle and Welsh, 1976). More recently Salamé & Baddeley (1982) studied the effects of discontinuous speech presented at 75 dB(A) on short term memory for visually presented digits. In each of their 5 experiments they showed a strong impairment of performance with degree of decrement related to the phonological similarity of the speech to the visually presented material. These experiments differed from most studies of the effects of noise in two ways. First the unattended speech was discontinuous while noise in most studies is presented

continuously. Secondly noise studies typically manipulate intensity whereas we had studied only one intensity, 75 dB(A) : we therefore decided to explore these possible differences in a study designed to explore within the same experiment the effects of noise and speech on visual immediate memory.

Experiments 1 and 2 explore the respective effects of continuous pink noise and unfamiliar arabic speech on immediate memory for visually presented digits and Exp. 3 tests on acoustic feedback masking hypothesis.

MATERIAL AND METHODS

The following Exp. 1 and Exp. 2 were totally identical except for their Noise and Speech SPL. A level of 75 dB(A) was used in Exp. 1 and a 95 dB(A) SPL in Exp. 2.

The visual memory task was the same as that used in the Salame & Baddeley (1982) experiment and comprised sequential visual presentation of [illegible] digits at a rate of 500 ms per digit with a [illegible] ms interval between successive digits. An acoustic warning signal occurred [illegible] sec before each series. Subjects then had 15 sec to give an immediate written serial recall. Each session comprised 30 series, of which the first [illegible] were [illegible] practice sequences.

In the control condition, Subjects were asked to rehearse [illegible] mentally but [illegible] overtly. They were instructed to repeat "Bla bla bla..." [illegible] the suppression conditions from the start of [illegible] until the end of each written recall. There were [illegible] rehearsal (mental / suppression) x [illegible] levels of [illegible] (Quiet, pink Noise and unfamiliar Speech) [illegible] design. A broadband pink noise was [illegible] the [illegible] unfamiliar Speech was made up from the Arabic [illegible] and recorded on a tape. Noise or Arabic [illegible] all the presentation period of the [illegible]. The Quiet conditions were at [illegible] dB(A). All [illegible] and carefully chosen as being totally [illegible] Arabic [illegible] to Exp. 1 and 24 others to Exp. 2.

RESULTS

Figure 1 represents the serial position curves for [illegible] involved in Exp. 1.

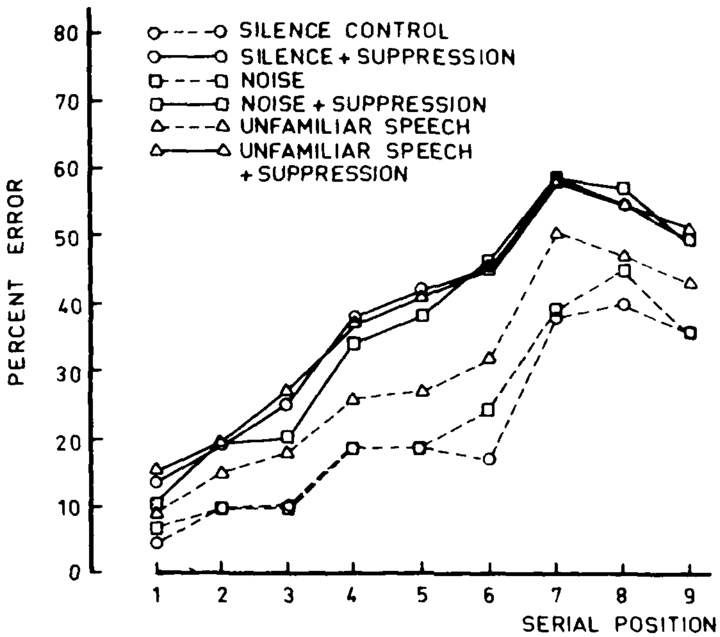

Fig. 1 - Respective effects of a 75 dB(A) Noise or unfamiliar Speech on Visual Short term memory in the control and suppression conditions.

The analysis of variance and a subsequent Newman-Keuls test lead to the following conclusions :

a) Pink *noise* does *not* seem to impair performances significantly when compared to the Silent control condition ;

b) Arabic speech produces a marked disruption of performances when compared either to the Silent control or to the Noise conditions ;

c) This disruptive effect disappears when the articulation is suppressed by repeating the irrelevant "Bla bla bla" during presentation and recall.

Comparisons made between respective conditions of Exp. 1 and those of

Exp. 3 in the Salamé & Baddeley (1982) previous studies did not show any marked difference. It appears then that the presupposed ON-OFF effect of discontinuous speech is not crucial. Moreover, the Arabic unfamiliar speech seems to be as disruptive as the unattended Subjects native tongue, which suggests that the visually presented STM material had been encoded phonologically in the non-suppression conditions as in the previous study (Salamé & Baddeley, 1982). It is possible however that the failure to observe a clear disruptive effect of noise may have stemmed from the low SPL used in Exp. 1. Exp. 2 tested this hypothesis by using a 95 dB(A) SPL. The results are reported in figure 2.

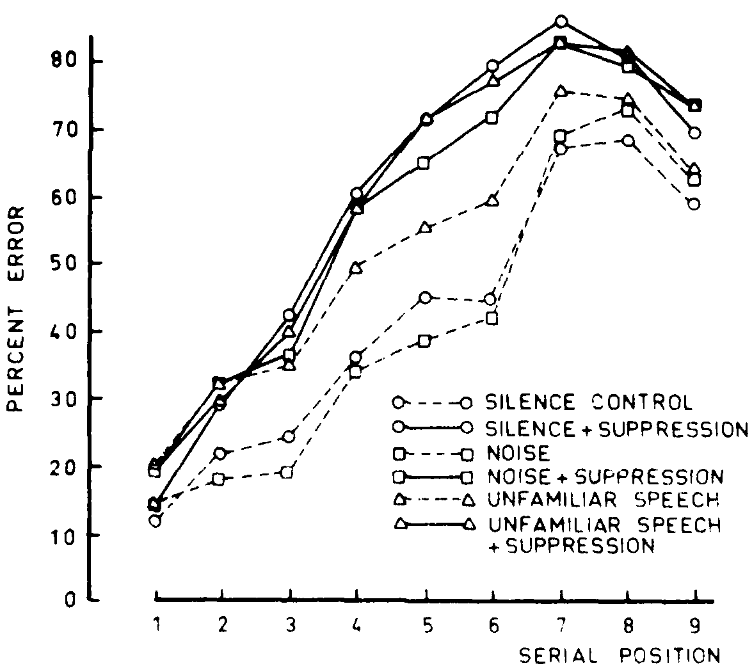

Fig. 2 - Effects of 95 dB(A) ambiant Noise or Speech on visual STM

The statistical analyses made on data of Exp. 2 lead to the same conclusions as that of Exp. 1, indicating that 95 dB(A) loud Noise did not markedly impair performances when compared to the Silent control condition, while Speech in an unfamiliar language did. It may be suggested that the results of Exp. 1 and Exp. 2 show however a general SPL effect since the error magnitude seems highier in Exp. 2 (95 dB(A))than in Exp. 1 (75dB(A)). Unfortunately the two Silence control conditions are also significantly different indicating that the two groups may by chance differed in memory capacity.

Other explanations of the lack of noise effects are possible however. Exp. 1 and Exp. 2 both used a latin Square design in order to counterbalance the order of conditions. This may have induced an asymmetrical transfer effect (Poulton, 1979) which could in turn have influenced the error rate in *the Silence control conditions*.

A second possibility is instruction based. While there is considerable evidence that articulation improves performances in Silence, things are less clear with loud Noise. The discrepancy between our results and other positive results could stem from our instruction to keep quiet in the control conditions. Other studies often leave the subject free to rehearse overtly. In this case, loud noise could mask the acoustic feedback (Poulton, 1977) or "outer speech" (Colle, 1980), hence impairing performance.

Exp. 3 tested this hypothesis by asking the subjects either to repeat the visually presented digits aloud, or to keep silent, according to the experimental condition. Acoustic conditions involved either a Silent [illegible] or a 95 dB(A) pink Noise. No unattended Arabic [illegible] were [illegible]. Moreover, an independant groups design was [illegible]

transfer between conditions.

EXP. [illegible] - MATERIAL AND METHOD

The material and the task were the same as in Exp. 1 [illegible]. Because of the separate groups design, the subjects performed the task for a Pre-test, always in Silence, before being assigned to one of the experimental groups. In the Pre-test, they were free from any articulation instruction. After the Pre-test, they were clearly instructed either to keep quiet or to repeat aloud each digit when presented, according to the experimental condition. A combination of 2 levels of rehearsal (Overt/Covert) x 2 levels of environment (Silence / Noise) lead to 4 rehearsal conditions: Overt in Noise, Overt in Silence, Covert in Noise and Covert in Silence. A 95 dB(A) pink Noise was presented continuously during the presentation of the digits. The Silence level was at [illegible] dB(A). [illegible] in each group were tested individually and they were paid for participation.

RESULTS

The error rate distributions across serial position in each of the four experimental conditions are shown in figure [illegible].

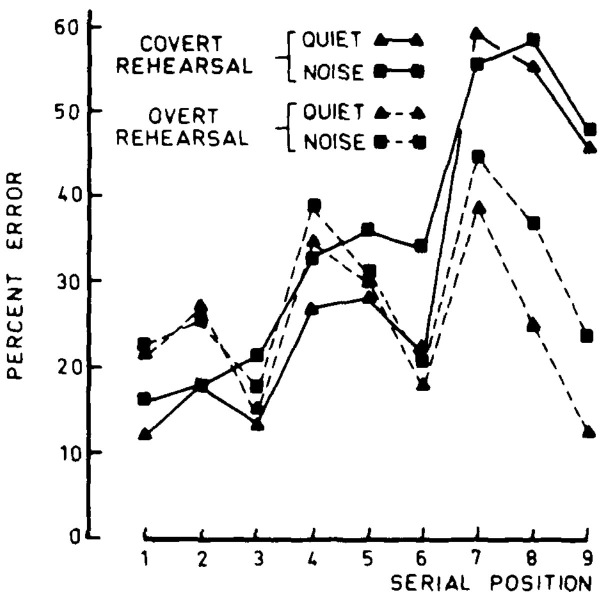

Fig. [illegible] - Effect of Noise and [illegible]

Analysis of covariance taking into account the Pre-test [illegible] effect of noise but a highly significant effect of art[illegible] (p [illegible]). This effect occurs mainly on the last [illegible]

These results allow one to draw the following [illegible] argue against the asymmetrical transfer hypothesis wh[illegible] ly suggested as a possible explanation of the resul[illegible] in which a latin square design has been used, [illegible] design of Exp. 3 lead to similar results showing [illegible] Second they do not give support to the interpret[illegible] overt acoustic feedback had been masked by noise [illegible] since articulating aloud lead to better performan[illegible] rehearsal, regardless of the presence of noise. Finally noise does not seem to mask inner spe[illegible] good in noise as in the Silent control, regardle[illegible] instructions.

CONCLUSIONS

Our results give evidence for a real effect [illegible] on memory for visually presented material. Exp. 1 [illegible] speech in an unfamiliar language presented at [illegible] immediate memory performance, while [illegible] that a 95 dB(A) noise did not lead t[illegible] when compared to silence. Exp. [illegible] ruled out two [illegible] terms of a possible asymmetrical transfer effect, [illegible] a hypothetical masking of the [illegible] feedback [illegible]

On the whole, our results [illegible] is crucial. Noise does not [illegible] mask inner spe[illegible]

interfere with the phonological coding or storage of the v[illegible] presented information.

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NOISE SLOWS PHONOLOGICAL CODING AND MAINTENANCE REHEARSAL: AN EXPLANATION FOR SOME EFFECTS OF NOISE ON MEMORY

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INTRODUCTION

Investigators began to examine the effect of noise on memory tasks in the 1970's and it was natural to attempt to explain the results in terms of arousal. However a careful examination of the findings reveals a pattern of results unlike those obtained using other arousal manipulations and which suggests that noise effects vary with task demands rather than operating on some memory component which is active in all short-term memory tasks. In the last few years we have obtained evidence suggesting that noise effects on short-term recall are due to interference with the acoustically-based operations involved in many such tasks.

BACKGROUND

Several experiments using different memory tasks have suggested that retention of the original order of items may be superior when they are presented in noise, though there are some contrary findings. It should be noted that the noise has

in most [illegible] have been white noise at [illegible] and [illegible] in the control condition and 75-95 in the experimental condition, occurring during stimulus presentation. Wilding and Mohindra (1980) reviewed these results and reported [illegible] of memory for the order of a fixed set of items, so no item recall was involved. Performance was superior for items presented in noise, especially when the set consisted of acoustically similar items. Millar (1979) also reported superior recall of order in noise, but the effect varied depending on the degree of prior experience and exposure to noise.

In the case of free recall of word lists, there seems to be little or no effect of noise on the number of items recalled but noise does sometimes reduce the degree of semantic organization at recall (Hörmann and Osterkamp, 1966, using noise at recall; Daee and Wilding, 1977, who obtained a non-linear relation; Smith, 1980; Smith, Jones and Broadbent, 198[illegible], who obtained an effect only in some conditions, which are discussed below.) Daee and Wilding found that the changes in semantic organization followed the opposite course to the changes in sequential recall, suggesting a link between the two, but Smith, Jones and Broadbent observed no changes in sequential recall. These findings suggest that noise induces a qualitative change in encoding and that overall improvement or deterioration in performance may depend on whether the task benefits from the type of encoding which is preferred in noise.

[illegible]

These results suggest several questions:

[illegible] change in rehearsal occurring in noise? In

particular, is there a change in inner speech or [illegible] maintenance rehearsal of verbal material in an articulatory loop (Baddeley and Hitch, 1974)?

2. If a change in rehearsal does occur in noise, does noise cause greater use of rehearsal and if so, why? That is, does noise induce a change of strategy and how could we explain this?

3. Alternatively, does noise affect rehearsal which is already occurring and if so, how? That is, does noise affect some basic component in the memory process?

4. Is the reduced semantic organization in free recall which is sometimes observed in noise due to an impairment of semantic processing? If so this might explain the increased dependence on maintenance rehearsal; alternatively it might be a consequence of the latter if the latter occurs for some other reason.

ANSWERS AND EXPERIMENTAL EVIDENCE

Our answers take the form of six claims:

1. Noise effects occur only if rehearsal is already present.

The best evidence for this appears in a forthcoming paper by Breen-Lewis and Wilding (1983); see also Lewis and Wilding (1981). Lewis and Wilding suggested instructions specifying a free recall test rather than a recognition test induced subjects to rehearse items in order. Breen-Lewis and Wilding found that noise only improved performance when subjects expected free recall but not when they expected recognition; in the former condition noise increased total recall and recall in the original order (see Table 1). This suggests that noise did not induce rehearsal in the group expecting recognition, [illegible]

did facilitate the rehearsal already present in the group expecting recall.

Table 1. Mean number of items recalled out of 20(N) and mean proportions recalled in the original sequence (S) under two levels of noise with different expectations about the memory test (data from Breen-Lewis and Wilding, 1983).

Noise level	65dbC		85dbC	
	N	S	N	S
Recall instruction	9.8	0.10	11.7	0.25
Recognition instruction	7.5	0.07	6.0	0.15

Other evidence supports this conclusion, such as Mohindra's (1983) demonstration that noise improved recall in order only when the presentation rate was relatively slow or a delay occurred before recall, both of which factors presumably permitted rehearsal. Also we have failed to obtain any noise effects when using visual patterns instead of words (unpublished).

2. Noise slows rehearsal.

Mohindra and Wilding (1983) tested the effect of noise on overt rehearsal of letter and word sequences. Noise slowed performance when subjects had to rehearse a sequence from memory but not when they had to read items repeatedly off a screen. This implies that some operation involved in retrieving the sequence from memory on each cycle was impaired.

3. Noise impairs access to a phonological code.

We have carried out two experiments (unpublished) to investigate whether the effect of noise on rehearsal can be related to an effect on access to phonological codes used in rehearsal. In the first experiment pairs of words were presented simultaneously and subjects had to judge whether they

rhymed. The words were taken from an experiment by Besner, Davies and Daniels (1981), who examined the effect of repeating an irrelevant word aloud (articulatory suppression) on this task., Suppression slowed the rhyme judgements and the authors concluded that it affected access to a postlexical phonological code, which is accessed via a store of known words, as opposed to a prelexical code which is accessed by applying rules of pronunciation to unknown or regularly spelled known words. However, since many of the words were regularly spelled this conclusion is not incontrovertible.

In our experiment with the same words performance was significantly slower and slightly less accurate in noise (mean latency 1.10s and 1.25s in the 65dbC and 85dbC conditions respectively, the error rates being 9% and 12%). In an attempt to identify the locus of the effect more accurately we changed the task so that words were presented successively and latency was measured from the onset of the second word. When the second word was an irregularly spelled word requiring post-lexical access to phonology, noise had no effect (see Table 2). When it was a non-word requiring use of rules to access pre-lexical phonology, noise had a significantly greater effect, as shown by a significant interaction between Noise and Word Type. However the noise effect on non-word judgements alone was not significant by an unplanned comparison.

Thus we cannot unequivocally conclude that noise affects access only to prelexical phonology unless and until the second result can be decisively replicated, but we can take the more

cautious claim that noise impairs access to some form of phonological code. We suspect that the postlexical code is basically articulatory and sensitive to articulatory suppression, while the prelexical code is basically acoustic. Besner et al (1981) found that suppression had less effect on rhyme judgments requiring prelexical phonology than those requiring postlexical phonology and Besner and Davelaar (1982) have since shown that, while suppression eliminates the effects of word length and acoustic (possibly articulatory) similarity on recall, it leaves untouched an advantage for non-words which sound like words (e.g. KWEAN) over non-words which do not sound like words. This shows that two codes exist, only one of which is sensitive to articulatory interference, while the prelexical code accessed by non-words is unaffected.

Table 2. Mean latencies in seconds (L) and percentage error (E) under two levels of noise for decisions that pairs of items rhyme (Wilding and Mohindra, unpublished).

Noise level	65dbC		85dbC	
	L	E	L	E
Word-Word pairs	1.16	11	1.16	13
Word-Non-word pairs	1.15	13	1.30	16

4. The effects of slower rehearsal depend on task parameters.

This is discussed by Mohindra and Wilding (1983) and we will only summarize the argument here. In tasks which induce a maintenance rehearsal strategy, slowing of rehearsal will reduce the number of items held in a rehearsal loop. This will often reduce the number recalled, but if the task is such that a major cause of recall failure is within-list confusion between items, a reduction in the number of items which are

rehearsed at any one time can improve recall on these items sufficiently to outweigh the loss due to holding fewer items. This situation only occurs in very restricted conditions such as remembering the order of a short list of items or holding the last few items in a running memory type task, precisely those tasks where improvement has been found in noise.

A simple model with just two parameters, the probability of confusion with other items in the rehearsal loop and the number of items held in that loop, confirmed these suggestions. Calculations from the model showed that recall of confusable items might benefit as the number held in rehearsal was reduced (as found by Wilding and Monindra, 1980, using acoustically confusable letters), while recall of less confusable items might be impaired as the number held in rehearsal was reduced, especially when that number was already small. This last prediction was confirmed by Mohindra and Wilding (1983) using nonconfusable words with a long pronunciation time; recall in order of the middle of five-word lists was adversely affected by noise.

5. Noise does not impair semantic processing.

Eysenck and Eysenck (1979) found no effect of noise on the speed of deciding whether a word was a member of any of a set of previously displayed categories. We have obtained a similar result when subjects had to decide whether a word had the same meaning as any of a set of previously presented words. We have also found that when subjects have to decide whether a letter string is a word or not, the degree of facilitation produced by a related preceding word is not affected when noise

is present (both these findings are as yet unpublished).

6. Noise affects semantic processing indirectly in free recall.

The evidence for this conclusion is indirect and inferential. Wilding, Mohindra and Breen-Lewis (1982) presented a list of words which were either unrelated or consisted of several closely associated subgroups. In some conditions they forced semantic processing by asking subjects to rate the pleasantness of the words.

With the unrelated list, noise increased total recall and recall in the original sequence, but if pleasantness ratings were required these effects reversed. With the associated lists, on the other hand, noise reduced total recall and use of the associations to organize recall (though not markedly) and again these effects reversed if pleasantness ratings were required. The condition with both ratings and noise produced the best results of all.

We interpret these results as follows. Subjects begin the task by rehearsing unless they are told to do something else. In noise they do this more slowly (and possibly more intensely) and this aids recall of unrelated lists. The rating task interferes with this strategy, but no semantic organization is possible in compensation. It is not entirely clear why addition of the rating task to noise is particularly harmful. With the associated list, maintenance rehearsal will give way to use of associations when these become apparent as list presentation proceeds, but the greater demands of rehearsal in noise will impede such a strategy change, probably because the possibility is less likely to be noticed. If the possibility is made more

obvious by forcing semantic processing, it is adopted in noise and used efficiently. We would point out in support that Smith, Jones and Broadbent (1981) have shown that when semantic organization of a list is obscure or very obvious, the effects of noise disappear.

CONCLUDING COMMENTS

There is little evidence on whether noise affects the extraction of and memory for information in prose. We (unpublished) obtained no effect of noise on either immediate or delayed recall of information in prose or inferrable from it. From the preceding argument we might expect little effect in so far as extraction of information from prose requires semantic processing, but holding sequences for processing could be affected (see Baddeley, Eldridge and Lewis, 1981).

Eyewitness accounts which depend primarily on visual processing should be unaffected by noise and conditions, but memory for speech may be affected, as well as speech perception.

Finally we must point out that there are other effects of noise which are clearly not accounted for by the factors identified in this research, such as effects on long term recall, retrieval from long term memory, vigilance, reaction time and dual tasks. In these cases explanations in terms of distraction or arousal may well be more fruitful.

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NOISE-INDUCED STRATEGIES DURING PHONEMIC AND GRAPHEMIC PROCESSING IN A MEMORY DUAL TASK.

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INTRODUCTION

The investigation on effects of noise on strategy changes or on attentional selectivity still seems to be in a controversial state (Hockey, 1970, 1978 ; Forster and Grierson, 1978 ; Hartley, 1981, a, b ; Forster, 1981). Yet there is a great need to elucidate these effects, not only for theoretical or methodological grounds, but also because of a pratical importance in real life situations.

The misperception or misinterpretation due to inadequate processing of visual stimuli such as danger signals, may, in many circumstances, potentially jeopardize human live. If it can be demonstrated that noise is a factor liable to reduce the processing of signals people consider as being less relevant to the task they are performing, then the issue must be considered careful .

In laboratory settings, the dual-task procedure constitutes a powerful means for the investigation of spontaneous strategic changes in the processing of task variables, when a subject is exposed to noise.

The present study was not primarily intended to investigate [illegible]

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changes, but rather to examine the effects of noise as a masker of the audio-articulatory feedback, when subjects had to process verbal material, either on a phonemic or on a graphemic level, with subsequent unattended or attended recall. Partially it was a replication of the [illegible] study, with the modification that a second session with attended recall was added and that in a second experiment, a graphemic instead of a phonemic word repetition modality was used. Furthermore, in either experiment, two independent groups of subjects were used, with one group performing in quiet and the other in noise. Results pertaining to these more theoretical aspects of the study will only be mentioned marginally and will not be discussed in the present paper.

MATERIAL AND METHODS

Material : In experiment 1, the stimuli were displayed visually via a Hunter card-master. Word stimuli were 20 equi-frequency words ; number stimuli were 20 four-digit numbers. In experiment 2, the stimuli were presented on a T.V. screen via a micro-processor Sinclair ZX81.

Procedure : The subjects were tested individually on a Brown-Peterson paradigm, using a distractor recall procedure. They were told that the experiment involved a short-term memory for numbers. On each of 20 trials, they were presented with the number for 2 sec. The number was then replaced by a word displayed for 2 sec. The subjects were instructed to repeat immediatly and overtly the word over and over at a pace given by a flashing lamp at roughly 1 repeat/sec, until the switching on of a nearby lamp signalled them that they were to write down the number. Then the next trial began. Each word was rehearsed for 6, 18, 36 or 60 sec. After completion of all 20 trials, the experimenter together with the subject proceeded to correct the answers for the number recall task. After this interpolated activity, a written recall of the rehearsed distractor words was then required.

In experiment 2, the same procedure was used with the difference that the distractor words were displayed repeatedly on the screen, at the same pace as the flashing lamp in exp. 1, and that the subjects were asked to say aloud the word "idem" in response to each repetition (articulation suppression technique) until the words were transformed into [illegible].

Noise : Speech-spectrum noise at a [illegible] dB(A) level was presented binaurally through closed-ear audiometric earphones. Previous experiments [illegible] shown that this kind of noise entirely masked the [illegible] feedback. All experiments were carried out in a sound-proof [illegible] with [illegible] dB attenuation.

Design and subjects: Two independent groups, [illegible], were used in either experiment. One group was [illegible] to the quiet condition, and the other to the noise condition. Each [illegible] underwent two sessions: the recall of the distractor words was unexpected in the first session, but was necessarily expected in the second. Care was taken to balance the per item rehearsal times within lists, and the serial position blocks of trials across subjects.

RESULTS

In experiment 1 (phonemic modality), under unexpected distractor word recall, roughly the same results as in the Rundus experiment were found: a monotonic increase in recall as a function of the rehearsal time. There was no effect of noise. When the results were analyzed according to the serial positions, a pronounced recency effect was found, but again no noticeable effect of noise.

An interesting feature comes from the results of expected recall in session 2. In quiet, the usual serial position curve was observed, with a marked recency and a less pronounced primacy effect. Noise led to a flattening of that curve, with essentially a removal of the recency effect. Such a phenomenon did not occur in experiment 2 (graphemic modality) where higher- yet not statistically significant- overall recall probabilities were found in quiet than in noise. All other comparisons led roughly to the same picture as in the phonemic modality.

Number recall performance: Individual error rates on number recall were recorded across conditions, [illegible] means (m) and standard deviations [illegible] are [illegible] table 1.

The error rates were [illegible], which [illegible] that the [illegible] word processing task left [illegible] recall task. As the [illegible] values, [illegible] $\bar{X}$ [illegible] [illegible]

tions as between-subject factors and [illegible] within-[illegible].
There was no significant effect of modalities , F [illegible] ; of condi-
tions : F (1 ; 56) < 1, and of sessions, F [illegible]. However, the
condition x session interaction was highly significant, F [illegible] ;
p < .005. Furthermore, the condition x modality x session interaction was
significant , F (1 ; 56) = [illegible] ; p < [illegible], which may be interpreted as a
smaller condition by session interaction in the graphemic than in the
phonemic modality. Yet for both modalities, the error rate decreased
between session 1 and session 2 when subjects were performing in quiet,
whereas it increased when they were performing in noise.

Modality	Phonemic				Graphemic			
	Quiet		Noise		Quiet		Noise	
Session	1	2	1	2	1	2	1	2
m	3.27	1.53	1.60	[illegible]	[illegible]	[illegible].47	[illegible]	[illegible]
s	2.55	1.96	1.96	1.78	[illegible]	[illegible]	[illegible]	[illegible]

Table 1 - Means and s.d. of errors produced in each [illegible] (max. errors = 20) for number recall.

DISCUSSION AND CONCLUSION

In session 2, when the subjects expected the distractor word recall, they had to carry out an extra processing which was to [illegible] and to hold the distractor words in memory. Nevertheless there was a drop in the error rates for number recall, in both phonemic and graphemic modalities, but only in the quiet conditions. This would suggest that in spite of extra processing, enough capacity was left for improving the performance in the number recall task. Whatever the origin of the improvement - strategy adjustment or mere practice - it should also be present under the noise condition. The results showed that the reverse occurred. Two [illegible] explanations could be forwarded :

1) A direct harmful effect of noise on some memory mechanism [illegible]

between the intake and the written recall of the numbers. In that case, there should also be a higher error rate in the first session under noise, when compared to the corresponding session in quiet. In fact, there was rather a lower error rate, as may be seen in table 1, though the difference between the results in the two conditions was not significant in either modality. Thus this explanation does not seem to be the correct one.

2) A noise-induced strategy resulting in the allocation of more processing capacities to that component of the dual task which the subject considers as having a higher priority and which is also more demanding, as it requires the storage of word items when auditory feedback is removed.

Conclusion : Although the present study was not initially aimed at investigating the strategy changes liable to occur when subjects were carrying out a dual memory task in noise, such a change has been clearly demonstrated in both experiments. We consider that a close analysis of data from dual task performances offer a good opportunity for the investigation of noise-induced strategic changes which seem to be a quite robust effect.

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THE AFTEREFFECTS OF ANTICIPATING NOISE EXPOSURE

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INTRODUCTION

During the 1973 conference in Dubrovnik, David C. Glass and Jerome E. Singer reported data from their classic series of experiments on the post-stimulation effects of exposure to noise (Glass & Singer, 1972; 1973). Specifically, they indicated that persons exposed to unpredictable, uncontrollable noise perform more poorly on tasks administered after noise termination than either those exposed to predictable and/or controllable noise or than those not exposed to noise. Glass and Singer tentatively concluded that exposure to unpredictable and uncontrollable noise produced aftereffects "because unpredictability and uncontrollability lead to a sense of helplessness which manifests itself as lowered motivation in subsequent task performance" (Glass & Singer, 1973, p. 414).

Seven years later, Cohen (198^) reviewed over 30 studies replicating and extending the Glass and Singer aftereffect work. The review indicated that the aftereffects of stress on performance occur as a consequence of a wide range of unpredictable, uncontrollable stressors including noise, electric shock, bureaucratic stress, arbitrary discrimination, density, and cold pressor. Hence, post-stimulation effects are attributable to the

unpredictability and uncontrollability of stressful events and not to some unique feature of noise or of any other stressor. Moreover, the two dozen noise studies clearly indicated that the physical parameters of the sound are relatively unimportant in producing aftereffects. That is, post-stimulation effects were found over a wide range of sound levels and types of noise. Cohen also concludes that aftereffects are not necessarily attributable to helplessness. Instead they may be wholly or partly due to psychic costs, shifts in arousal, overgeneralization of strategies evolved to cope with the stressors, and mood shifts associated with stressor exposure.

The present work is an attempt to gain further understanding of why exposure to unpredictable, uncontrollable stressors results in post-stimulation deficits in performance. Specifically, we are interested in determining the role stressor <u>exposure</u> plays in determining the effect. Glass and Singer's helplessness interpretation was based on the assumption that exposure to uncontrollable noise resulted in feelings of helplessness that interfered with performance on subsequent tasks. Other explanations offered for stressor aftereffects similarly assume a key role for exposure. For example, one approach argues that the effect is due to a fatigue that results from coping with the noise. Another that is a result of persisting in a strategy used during the noise period. In order to address this issue, we started with the most fundamental question about the relationship between exposure and post-stimulation effects. Is exposure necessary to produce an aftereffect? Hence we designed a number of studies in which we attempt to produce aftereffects without exposing subjects to the stressor. Our approach was influenced by recent work indicating that persons anticipating exposure to a stressor often behave as if they were actually exposed (e.g., Baum & Greenberg, 1975; Baum & Koman, 1976). The

premise was that the mere anticipation of exposure to aversive noise or other stressful stimuli would be sufficient to produce an effect. In short, if stressor anticipation is equivalent to stressor exposure, one would expect that same effects found after exposure to noise to occur after the mere anticipation of exposure.

The typical design of aftereffects research, as conducted by Glass and Singer (1972) and others, involves three conditions: a condition in which subjects are exposed to a stressor, a nonstressful comparison condition, and a third condition in which subjects are exposed to the stressor but told that they can, if they so desire, terminate the stressor (see Cohen, 1980, for a full review). Such perceived control has been found to ameliorate or lessen the negative aftereffects of stressor exposure. In the present study, this perceived control condition was added by telling one-third of the subjects that while they were going to be exposed to noise, they could decide to terminate it if necessary. Our hypothesis, in this regard, was that expectations of perceived control would alleviate the negative effects associated with expecting to be exposed to the noise.

METHODS

Subjects

Fifty-five female subjects were randomly assigned to one of three experimental conditions. All subjects were recruited to participate in "two separate, short experiments" that together would take half an hour. The experiments were to be conducted by different experimenters in different laboratory rooms in the same building. This instruction allowed us to separate the experimental manipulation (administered as part of the "first experiment") and the post-noise anticipation measure of performance (part of the "second experiment"). This prevented the possibility that a subject would expend less effort on the performance task because of her dislike for an experimenter who was going to expose her to an aversive sound or her dislike for the experimental situation in which this exposure would occur. Moreover, by keeping the second experimenter blind to the experimental condition, we were able to avoid the possibility of experimenter bias. Approximately half the subjects in each condition received one unit of extra credit for their participation; the remaining subjects were recruited through a local newspaper ad and were paid $3.00 for participation.

Procedure

Subjects were run individually. Upon arrival at the laboratory, initial measures of the subject's blood pressure and mood (on the Multiple Affect Adjective Checklist; Zuckerman, Lubin & Robins, 1965) were obtained. The experimenter then explained the subject's task (crossing out the letter "a" in columns of words). Approximately one-third of the subjects were also informed that they would be listening to bursts of noise played through headphones, while they worked on the task. The noise was described as the sound of a dentist drilling out a cavity, played at a sound level "about as loud as the level of a jackhammer if you walked past it while it was operating on the street" (NOISE condition). The subject was then presented with a pair of headphones and a consent form describing the experiment. Subjects were given several minutes to practice the task. During the practice session, they were given a sample burst of the noise (approx. 2 seconds at 100 dB(A)).

The perceived control manipulation involved treating another one-third of the subjects identically to the NOISE group. Additionally, these subjects were shown how a switch would turn on a light in the experimenter's control room. They were told that "although it is important for the sake of my research that you listen to all the noise...you may, if necessary, use this switch to alert me to stop the noise" (NOISE PC condition).

The remaining subjects were told only about the task of crossing out "As" (QUIET condition). Neither the consent form, nor the experimenter's instructions, mentioned the noise. They were told that they would wear a pair of headphones (unplugged) to block out any "extraneous distractions". They, too, practiced the task while wearing headphones.

The experimenter then gave the subject a questionnaire to answer which assessed their expectations about the noise and the degree to which they believed they would be able to terminate (control) it. While the subject was working on the questionnaire, there was a knock at the door. The experimenter answered the door and excused herself. A muffled conversation was held outside the door. This procedure was deemed necessary in order to lend credence to the procedures outlined below.

After approximately 1 minute, the experimenter rejoined the subject. The experimenter waited in the room until the subject had completed the experimental questionnaire, as necessary. The experimenter then announced that, due to scheduling problems and a backlog of subjects, there would not be enough time to do both experiments. Therefore, the subject would not have to be exposed to the dental noise after all. Even though they were relieved of having to listen to the noise, the experimenter explained that she wanted to go ahead and take their blood pressure and have them fill out some forms, as participants in the "second experiment" with the "other experimenter". The act of terminating the expectations in this manner provided the opportunity to measure the aftereffects of expecting exposure to aversive noise. Post-experimental interviews indicated that subjects believed the experimenter's excuse for not participating in the noise experiment. Support for the effectiveness of this instruction is also provided by previous studies in our laboratory that indicate decreased anxiety and depression among subjects relieved of the expectation that they will be exposed to a stressor (Spacapan & Cohen, in press).

All subjects agreed to this change in plans. The subject's blood pressure was taken and she again filled out the mood measure. The subject was then led to a separate room where the second experimenter (blind to the subject's experimental condition) administered a modified version of the Tolerance for Frustration task used by Glass and Singer.

In this version of the Tolerance for Frustration task, the subject is presented with two piles of line diagrams. Each pile is approximately 1 inch tall, and contains multiple copies of the same diagram. The diagrams are printed on 5 x 7 cards, and placed face down in front of the subject. The task is to trace over all the lines of the diagram without lifting pen from card and without tracing over any lines twice. The piles were placed in a specific order such that the subject would work first on an insolvable diagram and then on a solvable one. Subjects could take as many trials on a given diagram as they wished. The subject could choose to continue working on the same diagram, or move on the next pile (diagram) at any time, but could not return to a previous pile after proceeding to another. If the subject successfully completed the task for one diagram, she was to proceed to the next pile immediately. The total time allotted for the task was 10 minutes. The amount of time spent on each diagram was recorded . The more time spent on the insolvable diagram (Diagram 1), the greater was his/her tolerance for frustration (see Feather, 1961, for a full description of the task and its development). All subjects were then debriefed and had their height and weight measured (for use in the analysis of blood pressure data).

RESULTS

Manipulation Check

Data collected on the 7-point scales (were 1 = not at all, 7 = very) of the experimental questionnaire provided information on subjects' expectations of stressor exposure. Subjects expecting noise felt the experience would be more upsetting (NOISE $\underline{M}$ = 4.63, QUIET $\underline{M}$ = 1.47, NOISE PC $\underline{M}$ = 3.82; $\underline{F}(2, 50) = 33.41$, $\underline{p} < .001$) and more stressful (NOISE $\underline{M}$ = 4.53 QUIET $\underline{M}$ = 2.19, NOISE PC $\underline{M}$ = 3.59; $F(2, 49) = 10.50$, $\underline{p} < .001$) than subjects expecting the quiet condition. For both of these measures, post hoc comparisons by Scheffe´'s method reveal that QUIET is different from NOISE and from NOISE PC (all $\underline{p} < .05$), while the latter two conditions do not differ from one another. In addition, NOISE subjects felt more nervous (NOISE $\underline{M}$ = 3.05, QUIET $\underline{M}$ = 2.06, NOISE PC $\underline{M}$ = 2.47; $\underline{F}(2, 49) = 3.43$, $p < .04$) about the experiment than the other two groups. Post hoc comparisons by Scheffe´'s method revealed that in this case, QUIET differed from

NOISE ($p < .05$). While the mean for the NOISE PC group fell between the NOISE and QUIET means, it did not differ from either.

Subjects who expected exposure to noise also answered a scale assessing the degree to which they felt free to have the noise stopped. While subjects who expected to be able to control termination of the noise felt more free (NOISE PC $\underline{M} = 4.23$) than subjects without control (NOISE $\underline{M} = 3.79$), the difference was not significant.

Tolerance for Frustration

Time spent on the insolvable diagram (#1) was the measure of frustration tolerance; the less time spent, the less tolerance. An analysis of variance on this measure revealed an effect of the manipulation ($F(2, 52) = 6.13$, $p < .01$). Subjects who expected the noise without control spent a mean of 281 seconds on the task, while those expecting to be able to control the noise spent a mean of 437 seconds and those not expecting noise exposure spent a mean of 425 seconds. Post hoc comparisons by Scheffé's method support the fact that while the NOISE group was different from the QUIET group and the NOISE PC group (both $p < .05$), the latter two conditions did not differ from one another.

Blood Pressure and Mood

There were no effects of the experimental manipulations on these measures.

SUMMARY AND GENERAL DISCUSSION

When subjects' expectations of noise exposure were terminated, decreased frustration tolerance was observed in those subjects who had expected stressor exposure. Moreover, the expectation of control over stressor termination lessened the negative impact of stresser expectation <u>after</u> the anticipation period. In sum, it is apparent that there are

aftereffects of the anticipatory period that are similar to those produced by actual exposure to noise. It is noteworthy that we have found similar aftereffects of the anticipation of immersing one's hand in ice water (Spacapan & Cohen, in press).

It is not totally clear why there were no differences in blood pressure and mood by experimental conditions. It could be argued that these measures are only affected by actual exposure to noise, and not by the anticipation of such exposure. It should be noted, however, that studies of post-stimulation effects have not consistently found effects on these measures, while work with the tolerance for frustration task has been consistent.

The present research raises two important issues. First, it is unclear what mechanism is responsible for the observed decrease in tolerance for frustration. Second, given the demonstration of the powerful nature of stressor anticipation, one might question the actual contribution of stressor exposure in producing "poststimulation" effects.

Possible Mediators

Heightened arousal, negative mood, and attentional overload are a few of the explanations that have been offered for the poststimulation effects of stressor exposure (see Cohen, 1980). It is noteworthy that aftereffects of the anticipation period were obtained in the absence of evidence for these possible mediators. First, neither self-report nor physiological data support a heightened arousal hypothesis. Moreover, there was no evidence that either self-reported stress, or blood pressure were affected by the expectation of control. Second, the lack of differences between stressor conditions in self-reported mood suggest that mood is likewise unaffected by the anticipation of stress exposure, and hence plays a minor role (at best) in producing the frustration tolerance effects.

Finally, it is difficult to argue that attentional capacity was seriously depleted in the present research, given the brevity of the anticipation period and the absence of task demands during the anticipation period.

There are a number of explanations offered for the post exposure effect that are consistent with these results, although there is no direct evidence that they are applicable. For example, it is possible that those anticipating exposure to uncontrollable stressors use coping strategies during the anticipation period and maintain these strategies even after the expectation is terminated. Although a particular strategy may be adjustive during the anticipation period, it may interfere with task performance after expectancy termination (cf. Cohen, 1980). Similarly, a preoccupation with the threatening situation may persist to some degree after expectation termination resulting in distraction that affects performance on post-anticipation tasks.

It is worth noting that the fact that we find effects of anticipation that are analogous to the effects of exposure does not definitively indicate that these effects are mediated by the same mechanisms. However, the similarities are striking and such an assumption is not unfounded at this point.

Poststimulation vs. Postexpectation Effects

Is it possible that previously observed poststimulation effects are really "postexpectation" effects? We have demonstrated that stressor expectations are sufficient to produce aftereffects. Given this demonstration of the powerful nature of stressor anticipation, one might well question the actual contribution of stressor exposure in producing stressor effects. In other words, it is possible that both during-exposure and

after-exposure effects reported in the literature are wholly or partly attributable to residual effects of the anticipation period. While expectations of stressor exposure are *sufficient* to produce aftereffects, it remains for further research to demonstrate whether the manipulation of stressor expectation is *necessary* to produce similar effects during and after stressor exposure.

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SEX, AROUSAL AND FATIGUE DETERMINING NOISE EFFECTS AND AFTEREFFECTS

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INTRODUCTION

Recent experiments in our laboratory and others have indicated that the effects of noise are complex, varying as a function of task, noise characteristics and significance, onset time, time of day, and gender of the subject.

This obviously is not the place for a comprehensive review of previous findings on noise effect or theories of underlying mechanisms but we do need to recapitulate somewhat. Among the effects reported are differential performance on primary and secondary tasks, changes in detections on vigilance tasks or altered response criteria, memory impairments, and aftereffects indicative of lesser perseveration. Among the aftereffects reported by Glass and Singer (1972) is reduced perseveration on the insoluble portions of the Feather task, which involves tracing geometrical designs. Other performance effects often have not been replicated; there also are some social aftereffects such as aggression and reductions in helpfulness (Broadbent, 1979). Performance deficits have been attributed to conditioned helplessness

(Glass and Singer, 1972) or perceptual overload and consequent cognitive fatigue (Cohen, 1978). Noise characteristics are critical; normal aircraft noises which have gradual onset do not produce the effect while those with abrupt onset do (Percival & Loeb, 1980) but abrupt onset white noise bursts on the same intermittent schedule do not. Effects are increased when speech is meaningful, so that the usual Glass and Singer noise, a composite of machine noise and unintelligible speech, though it had more effect than white noise, has enhanced effects with loud meaningful speech (Rotton et al, 1978).

The research which I shall discuss involves arithmetic computation during or following noise. Some has been reported in articles published or in press but we have not previously tried to synthesize our findings into one comprehensive view. Apparently simple paper and pencil computation is unaffected by noise (Park & Payne, 1963). When there also is a memory requirement noise bursts produce a deficit (Woodhead, 1964). With the Norinder task, which requires simple decisions as to when to add and subtract, noise reduces number of problems attempted (Frankenhaeuser & Lundberg, 1977). These latter experiments utilized male subjects and were run in the morning. Our experiments have been aimed at extending the generality of the findings to both sexes, other times of day, and different tasks.

EXPERIMENT 1: NOISE AND SELF PACED COMPUTATION

Our first experiment (Loeb, Holding, and Baker, 1982) extended the Frankenhaeuser and Lundberg study. We measured performance for 44 men and 44 women on the Norinder task, either between 8 and 10:00 A.M. or 4 - 8:00 P.M., in 55 dBA ambient or 95 dBA white noise for 50 minutes. Men completed significantly more problems in the quiet than in the noise in the A.M., confirming Frankenhaeuser and Lundberg. However in the P.M. a small and non-significant difference in the opposite direction was noted. (This is shown in Figure 1.) For women the differences were entirely opposite but not significant statistically. Errors were relatively infrequent and uninfluenced

by the experimental variables. So it might be said that noise slowed men in the morning and made them less efficient, but this did not happen in the evening or for women.

EXPERIMENT 2: RAPID COMPUTATION IN NOISE WITH COMPUTER PRESENTATION

In a second experiment (Baker, Holding, & Loeb, in press) 24 young men and 24 women were presented with digits on a cathode ray tube, one at a time, at rates ranging from 2 - 4/second, with the digit string length set at 6, either between 8 and 10:00 A.M. or 4 and 6:00 P.M. Subjects had to compute totals and respond within 10 seconds; presentation and scoring was accomplished with a DEC PDP 9 minicomputer. Figures 2 and 3 show the most important results. In the morning men were faster and made more errors in noise than in quiet. In the afternoon they were faster and made more errors in quiet than in noise. In brief, effects of noise for men in the morning, which suggest a speed-accuracy tradeoff, reverse in the afternoon. Moreover the entire effect is opposite for women. Interactions for sex, time of day, and noise are significant ($p < .05$ for RT, $p < .05$ for errors.)

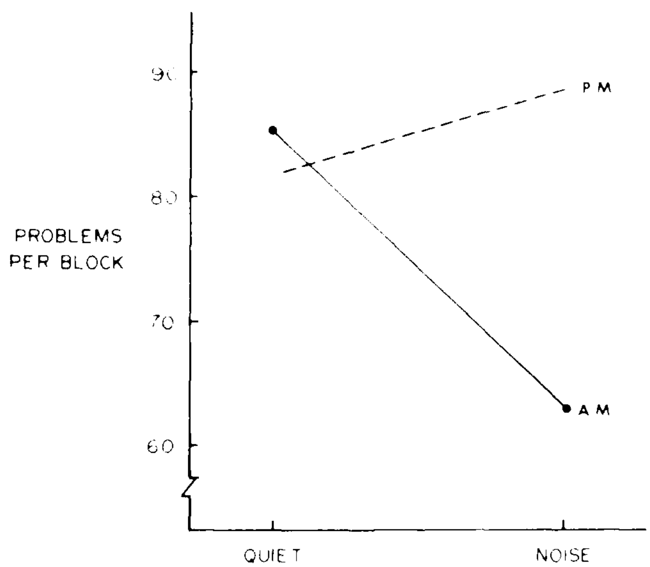

Fig. 1 - Effects of noise and time of day on rate of work by men (Norinder task)

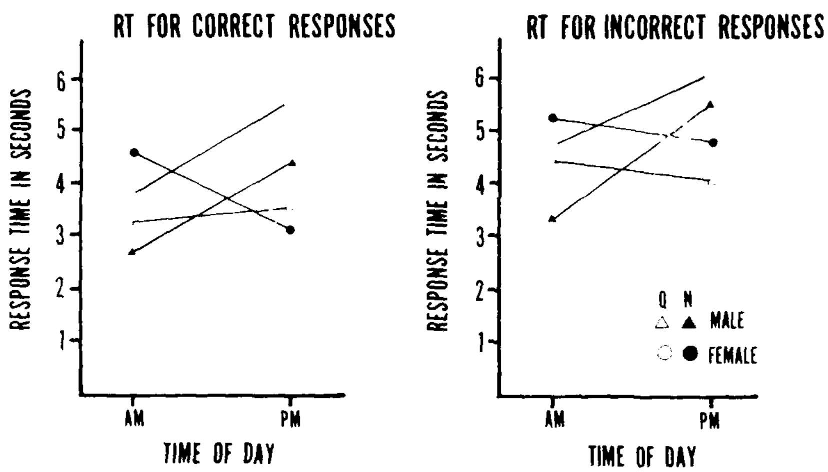

Fig. 2 - Effects of noise, time of day, and subject sex on speed of response in rapid computation

DISCUSSION OF EXPERIMENTS ON COMPUTATION IN NOISE

In one way the noise effect on the rapid computation task is opposite to that observed on the Norinder, at least so far as speed is concerned. The tasks are quite different: instructions emphasized speed (finishing more problems) in the Norinder and significant effects were noted only for speed. The rapid computation, computer-controlled task emphasized accuracy, but speed is a factor in two ways--the numbers were presented quite rapidly, and the subject had to respond in a limited time (10 seconds). Assuming the Norinder to be primarily a speed task and the rapid computation

task primarily an accuracy task, one might argue that effects on efficiency in the two tasks are similar. This doubtless oversimplifies the findings. One can say that there are are complex interactions of noise, time of day, and gender on both tasks.

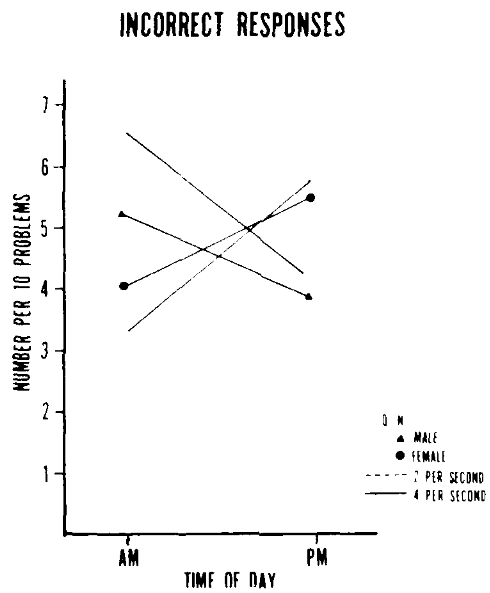

Fig. 3 - Errors in rapid computation as a function of noise, sex, and time of day

We do not understand, either, the difference in the results for men and women. However we do have temperature data from women (Baker, unpublished) which suggest that circadian variation in arousal is somewhat different in women.

NOISE AFTEREFFECTS AND FATIGUE

The secondary task technique has been used to assess fatigue (Bahrick et al., 1952), noise (Hockey, 1970) and other stressors

(Bursill, 1958) and effects are generally similar. This suggests a common mechanism. Reduced perseverance on the Feather task following noise-and-work also might reflect fatigue. A secondary explanation advanced by Glass and Singer (1972) attributed the effect to an overloading of information-processing capacity when noise is present, a concept, which might be viewed as related to Cohen's (1978) cognitive fatigue hypothesis. It appears more related to earlier concepts of narrowing of attention by stress (Bursill, 1958; Hockey, 1970a,b) than conventional notions of fatigue.

Holding, (1983) in a recent review of the concept of fatigue, has emphasized the role of aversion of effort and of the tendency of tired subject to "cut corners". As a measurement paradigm ("COPE") he has suggested presenting a situation, preferably resembling that which fatigued the subject, in which the subject chooses one of several routes to a task goal, differentially loaded for effort and probability of success. He predicted that the fatigued subject would shift toward lower effort at the cost of lowered probability of success. Several experiments were described substantiating this concept. If the concept is valid, and noise and fatigue activate similar mechanisms, a similar methodology should be applicable to the noise situation.

EXPERIMENT 3: NOISE and "COPE"

Our third experiment (Holding, Loeb, & Baker, in press) adapted the COPE paradigm to measure noise effects on arithmetic. The task required subjects to choose between lists of double-digits of varying lengths in which they were to find a consecutive pair adding to a target sum. Longer lists involved more addition operations to establish the presence of the sum but also more probably contained the sum. Lists contained either 7 double-digit numbers (6 possible additions) or 5 such numbers (4 additions) or 3 (2 numbers)--the ratio of operations being 3 to 2 to 1. Eight groups of 12 subjects first performed one practice block of 6 trials, then

three scored blocks. Four groups then were exposed to 30 minutes of 95 dBA white noise (Noise) and four to 55 dBA ambient sound (Quiet). During exposure half the groups worked on the Norinder task and half read at will. All subjects then were given 3 scored blocks of 6 trials on COPE. Half of those experiencing Noise exposure during Norinder work or reading worked COPE in noise and half did so in Quiet. This was also true for those working on Norinder or reading in Quiet. One would predict that noise or work would shift COPE performance after exposure in the direction of a shift in choices to those lists that are shorter, involving less effort, with a lesser probability of containing the target number.

Figure 4 shows the shift in choice of lists, in terms of drop of choice in the predicted direction. A shift from an average choice of the long list to an average choice of the medium list would be a shift of +1.0; a shift in the opposite direction, -1.0. Note that while the shifts are small generally they are in the direction predicted. There was a sizable shift for work alone, for subjects working and post-tested in Quiet. Interestingly, noise alone seems to produce a shift in that direction, but a smaller one, while noise following work abolished the expected shift. This is in line with another of Holding's formulations, that a change in circumstances often works the same as a rest. Working in Noise and post-testing in Quiet produced a larger shift than working in Quiet, and working and post-testing in Noise produced the largest shift indicative of fatigue effects.

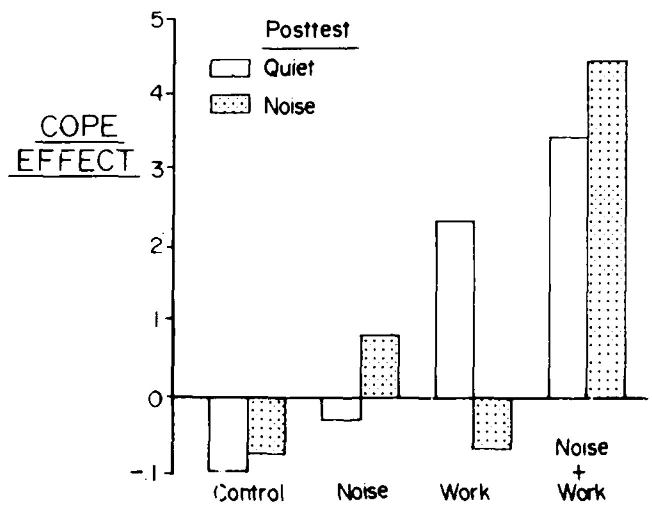

Fig. 4 - Changes in choice between pretest and posttest, due to noise or work or both, with or without noise in posttest

A recent related experiment by Lysaght et al at the University of Cincinnati (not yet published) investigated the effect of low level (70 dBA) and high level (90 dBA) continuous white noise and continuous Glass and Singer noise on low- and high-demand cognitive visual vigilance tasks and subsequent aftereffects on the Feather and arithmetic COPE tasks described above. Noise had no effect on the low-demand task. Low-level white noise enhanced performance (detections) on the high-demand vigilance task but at high levels left performance unchanged. The continuous Glass and Singer noise produced a progressive impairment on this task at the low level and a greater but stable impairment at the high level. Both vigilance tasks produced a significant shift in COPE choices similar to that described above but noise level during vigilance did not affect either COPE or Feather. The lack of effect on Feather tasks is in line with previous findings on continuous white noise. Lack of effect of noise on COPE may reflect the difference in work task in this and the previous situation or other special conditions of the experiment.

Our subsequent COPE experiments have been aimed at determining the presence and nature of interactions of work and noise with sex and time of day. To "improve" our procedure and eliminate experimenter effects, we first tried computerizing COPE. For our purposes this seems not to be an improvement; it abolishes effects, possibly because of subject fascination with computerized tasks. Other minor alterations such as group administration also alter results. We have therefore returned to our original task and are investigating the interactions of interest.

INTERPRETATIONS

What are we to make of all this? In an earlier publication (Baker et al, in press) we concluded that the effects of noise are different from arousal. Many of the present findings support this conclusion. The results reported by Lysaght et al--effects of different types of noise on different types of task--might be interpretable in terms of arousal.

One problem is that our terminology is confused. Arousal is an effect or a complex of effects; noise, caffeine, time of day and other variables manipulate it (them) and produce other effects. There is good physiological evidence that noise and other sensory input has certain activating properties. On the other hand as Broadbent (1971) and others have pointed out, continuous noise,

especially at moderate levels, may by masking insulate us from stimuli that would otherwise activate us. Intense noise also produces emotional reactions which vary with the individual. While this is sometimes described as activation, such a view is doubtless over-simplified. The conditioned helplessness view, which remains to be validated, would also represent an emotional effect. It is not unreasonable to believe that emotional reactions and the necessity to inhibit response to distraction produces fatigue; this might be evidenced as a lesser tendency to observe over a wide range and a reduced tendency to exert effort. There may also be effects of noise on short-term memory, though they are complex and not well understood. Our data are not readily interpretable in these terms.

While it would be desirable to explain noise effects in terms of a single mechanism, it probably is unparsimonious to do so. It is very difficult to tease out the multiple effects of noise, but we must continue to try.

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THE EFFECTS OF NOISE ON STRATEGIES OF HUMAN PERFORMANCE

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Recent studies have shown that moderate intensity noise does influence performance (e.g. Daee and Wilding, 1977; Eysenck, 1975; Hamilton, Hockey and Rejman, 1977; Jones, Smith and Broadbent, 1979; Millar, 1979; Smith, 1982, 1983; Smith, Jones and Broadbent, 1981; Wilding and Mohindra, 1980). However, most theories which suggest that human performance is shifted by noise in an invariant or mechanical fashion have been shown to be inadequate. This is largely because experimental studies have shown that changes in the difficulty of the task, changes in the probability of need for action, and changes in the subject's prior experience may abolish or even reverse certain effects (see Smith, 1982; Smith and Broadbent, 1982, and Smith, Jones and Broadbent, 1981, for a detailed discussion of this point).

Many of the tasks which have shown effects of moderate intensity noise have used verbal materials and this made it initially attractive to think in terms of an effect of

noise on internal speech (see Poulton, 1977; and Broadbent, 1978). However, verbal tasks often present the subject with several strategies of doing the task and noise may change the relative efficiency of performing in one way rather than another. Hamilton, Hockey and Rejman (1977) suggest that in noise there is a faster throughput of information but reduced short-term storage. This view was supported by the results from two experiments. A study of "closed system thinking" showed that there was a slight benefit to be had in adopt different recall strategies to subjects in quiet (see Smith, Jones and Broadbent, 1981). Smith (paper submitted, a) has shown that noise may influence which aspects of complex stimuli are successfully recalled. He carried out an experiment on the effects of noise on recall of global features and local detail, and he found that in quiet subjects showed a bias in favour of recalling global features whereas subjects in noise showed a preference for local detail. The subjects were shown lists of stimuli like the one below (a large letter made up of small letters) and they had to recall both the large and small letters.

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M
M
M
M
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When noise was present subjects correctly recalled more small letters than large letters. This effect has some similarity to the 'funnel vision' effect which has often been reported (see Broadbent, 1979).

Changes in task parameters often remove these noise-induced biases and it seems obvious that the choice of strategy will depend on features of the task other than the noise, and this plausibly explains why changes in the details of experiments change the strategy used and hence alter the noise effect. Smith, Jones and Broadbent (1981) found that in certain experiments noise reduced the amount of clustering in free recall, and this effect was found to be due to recall in noise consisting of fewer words in the initial clusters

was impaired when there was a high storage load. In a running memory task they found noise improved recall of the most recent items but impaired recall of items earlier in the list. How can this approach deal with the variation in the effects of noise? If noise alters the relative efficiency of certain processes or stages of processes then certain results will be obtained when these processes are used a great deal and other results will be obtained when they are not used or when they are used to a lesser extent. This type of theory is referred to here as a "<u>hidden defect theory</u>", and the noise-induced defect in the running memory task is the reduced storage capacity. This suggests that the effects of noise on running memory will depend on whether there is a high or low memory load, and, indeed, Smith (in press) has shown that Hamilton <u>et al</u>.'s results are only obtained in high memory load conditions.

Recently, Smith (1982) has put forward an alternative view of the effects of noise on performance and he has sug-

gested that when subjects carry out a task which can be performed in several different ways, noise may lead to the adoption of certain strategies in preference to others. This type of theory can be distinguished from the hidden defect theory and is *referred to here as* <u>strategy choice theory</u>. Some examples of noise influencing the choice of strategy will now be given. There is evidence that subjects in noise may adopt a maintenance rehearsal strategy rather than an elaboration strategy (see Pace and Wilding, 1977). There is also evidence that subjects in noise may

and greater subsequent recall of individual words. This recall strategy did not occur if either the word lists contained very weak instances of categories (initial clustering was greatly reduced in this condition) or if exhaustive categories were used (all words from the category tended to be recalled in one cluster, hence there was little or no subsequent recall of individual words). In these two conditions there was no reduction of clustering in noise.

In many tasks it is obvious that one strategy should be used in preference to others. A strategy may be dominant because of instructions, previous experience, or some feature of the task. Recent studies by Smith (1982) and Wilding, Mohindra and Breen-Lewis (1982) have shown that noise may reinforce the use of the dominant strategy. This view fits in well with earlier conclusions about the general effects of noise-induced arousal. Broadbent (1971) suggested that high arousal increased the probability of sampling information

from dominant sources. Recently, the theoretical basis for studying the effects of noise on performance has been substantially revised and attentional selectivity is no longer a mechanistic response to noise but is an aspect of the strategies adopted by the subject, not only in response to the noise, but as a function of all experimental conditions. Smith (1982) suggests that in noise the allocation of effort moves towards the operation which appears to best repay the investment of more effort. Given a complex task those parts which are affected by noise are determined by a complex combination of factors such as difficulty, instructions and the salience of the stimuli involved in the task. Verbal tasks are particularly sensitive to noise effects because they offer a variety of strategies, and shifts of dominance or preference can occur more easily than in data-driven tasks.

Some recent studies by Smith (papers submitted, b and c) have examined resource allocation in noise by studying combined performance on pairs of tasks. The difficulty of each task was varied, so was the probability of doing each task, and also the priority of the tasks. The results showed that the effect of noise depended on the extent to which the two tasks competed for common resources which could be actively allocated to one task or the other. For example, when a cognitive vigilance task was paired with a proportion estimation task it was found that noise impaired performance on the vigilance task but had no effect on the estimation task. This effect of noise was not altered by

changes in the task parameters. Performance on the vigilance task was influenced by changes in task parameters, especially priority instructions (when it was the high priority task there was a large improvement in performance whereas when it was the low priority task performance was impaired). Performance on the proportion estimation task, on the other hand, was not influenced by priority instructions or changes in difficulty and probability. This task can be considered to involve passive, automatic processing which is not improved by the allocation of extra conscious effort.

When the vigilance task was carried out with another task which was influenced by changes in parameters, a running memory task, a completely different pattern of results was obtained. In this experiment the two tasks competed for the same resources and when the vigilance task was the high priority task there was an improvement in this task and impairment in the running memory task. The opposite pattern of results occurred when the running memory task was given high priority. The nature of the noise effect was altered by changes in the task parameters. For example, when there were no priority instructions noise impaired performance on the vigilance task but this effect was removed when the vigilance task was given high priority. These results provide some support for the view that noise may influence the allocation of processing resources, although they also suggest that these effects only occur with

certain types of task or task combinations.

The distinction has been made between passive, data-driven or bottom-up models of human information-processing and active, resource driven or top-down models. The latter type of model would seem to form the more coherent explanatory basis of the effects of noise on performance, and this applies to tasks using both verbal and non-verbal materials. Most of the preceding account has been concerned with tasks using verbal materials. However, Rabbitt (1979) has shown that the effects of noise on the five-choice serial reaction-time task (an increase in errors and/or gaps but little effect on the average reaction time) can be explained in terms of noise producing inefficient control of the *speed-error* trade-off function.

The effects of noise on the control processes may reflect initial coping with a task and may disappear when practice shows which is the most suitable method of doing the task. However, effects of noise may also be long lasting and even transfer to quiet conditions. Asymmetric transfer effects are well documented in noise research and it is of major interest that a recent account of asymmetric transfer considers the effect to represent a transfer of strategy (Poulton, 1982). The effects of noise on the control processes may transfer from one experimental condition to another. For example, Smith (paper submitted, d) investigated the effects of noise on recall of strong and weak associates. The rationale behind the experiment was [illegible]

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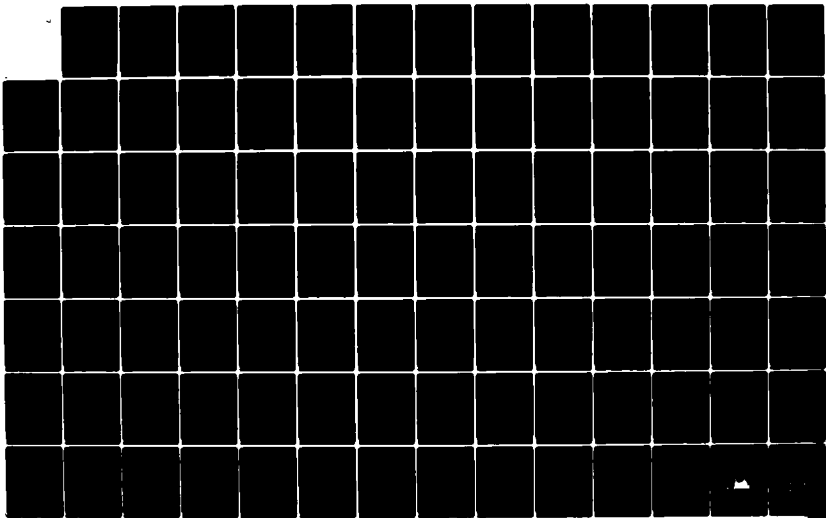

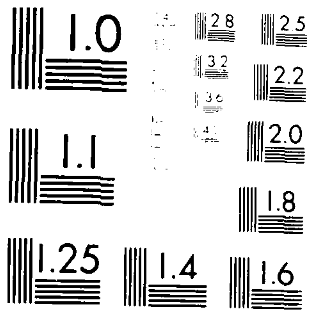

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noise should increase associative recall when this was an obvious strategy to use (when the lists consisted of strong associates) but not when recall by association was a less obvious strategy (when the lists consisted of weak associates). Subjects were shown two lists of words and the first list consisted of strong associates and the second list consisted of weak associates. As predicted, noise increased associative recall in the first list. However, associative recall was also better in noise for the second list and this reflects the transfer of strategy from one condition to another.

In another experiment, Smith (paper submitted, e) investigated the effects of noise on a biased probability choice reaction time task. Each subject carried out three blocks of trials in noise and quiet: in the first block the three light sources occurred with equal probability, whereas in the second block of trials one light occurred more frequently than the other two. In the third block of trials equal probabilities were again used. There was no effect of noise on the first block of trials but in the second block noise reduced the reaction time to the high probability source but increased it to the lower probability source. This effect continued into the third block (the light which had been the high probability light was still responded to more quickly in noise and the other lights were responded to more slowly even though they now occurred with the same probability), and this shows that effects of noise on the

control processes can last for some time. This suggests that subjects in noise can often be considered rather inflexible, and further studies are required to see how noise influences subjects' ability to adapt to rapidly changing tasks.

At the moment it is still unclear why noise alters the efficiency of the control processes and why it produces various strategy changes. These effects may reflect some underlying change of state, such as a change in arousal level, or they may reflect an attempt by the subject to maintain competent performance (see Jones, 1983). It would also be desirable to know which effects are specific to noise and which effects are also produced by other factors. Broadbent (1971) produced two rough classes of variables affecting performance. One class included noise, sleeplessness, amphetamine and phenothriasines. Another class included alcohol, time of day, barbiturates and the personality dimension of introversion-extraversion. Broadbent suggested that some variables (the first class listed above) affect well-established processes whereas the other class of variables affect a higher level which monitors and controls the other level. The present account suggests that Broadbent's classification needs to be modified because noise appears to affect the upper level rather than the lower level. Further information about other variables and their interactions should clarify this issue and show whether all of Broadbent's classification needs to be turned around or

whether noise alone needs re-classifying.

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LOUD NOISE AND LEVELS OF CONTROL: A STUDY OF SERIAL REACTION.

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INTRODUCTION

Among the range of tasks that have been shown to be sensitive to the effects of loud continuous noise, that of serial reaction is one of the most prominent. Typically, loud noise increases the number of errors (e.g., Broadbent, 1971) accompanied sometimes by an increase in the number of unduly long responses, known as 'gaps' (e.g., Hartley, 1973), these effects becoming more pronounced as the task proceeds. In several articles Poulton (e.g., 1981) has argued that the typical experimental outcome can be accounted for in terms of the interplay of the arousing and masking qualities of noise. There is an initial beneficial effect caused by an increase in arousal, followed by a gradual decline in performance to the pre-exposure level as the task proceeds. Performance declines sharply when the noise is switched off, as arousal drops below the norm, giving a so-called after-effect of noise. For tasks which contain an element of acoustic feedback, the increase of masking in loud noise acts jointly with the action of arousal.

Without the action of arousal, masking would produce a deleterious

effect spread uniformly over the period of exposure. Loud noise increases the difficulty of discriminating between responses (that take the form of taps with a metal stylus) which hit the target and those which just miss the target. This problem of discrimination leads to an incidence of double-taps: the first (correct) response is perceived as a miss and gives rise to a second ill-considered stab at the same response, without a check on the state of the display. Although errors of both long and short latency can be accounted for by this mechanism, it seems unsound to do so. Evidence from studies of serial reaction in other contexts reveals that repeated response are rather fast and that responses that serve to signal or correct an error are also fast (see Rabbitt, 1979).

Although loud noise makes the discrimination of acoustic cues more difficult, this is overcome in the early stages of exposure by the high level of arousal. Arousal encourages the subject to tap harder until fatigue sets in. At this stage performance falls below the norm. Perhaps the most surprising expectation is that tapping harder will not have repercussions for the speed of response. An increase in intensity of 30 or 40 decibels from a small non-resonant disc is likely to incur a cost of speed and accuracy.

The task used here differs in several ways from that traditionally employed, such modification being designed to reduce the magnitude of acoustic cues. Large ballistic movements were eliminated by the use of a 'piano-key' type of keyboard. The main means of reducing acoustic cues was by means of ear-defender headphones which allow white noise to be presented at the ear while offering attenuation in excess of 40dB to ambient sounds. Aside from the primary interest in the effects of removing acoustic cues, the present experiment also focused on

performance in the period following exposure. In Poulton's terms this is a period when arousal falls quickly below the norm. Several competing explanations are nevertheless tenable. All are to some extent predicated upon the relationship between performance during and following exposure (see Jones, Auburn and Chapman, 1982). The after-effect was studied in the present case by observing serial reaction performance for 40 minutes with noise at either 90 or 60dBC for the first 30 minutes with the remaining 10 minutes being conducted in quiet.

MATERIAL AND METHODS

Subjects.

Thirty-two students were paid a small sum for participating in the experiment. Subjects were screened audiometrically.

Equipment.

The serial reaction task was made up of four keys with, at the distal end of each key, a stimulus light. Depression of a key operated a 'Hall-effect' switch which produced minimal acoustic and electrical interference. Each key-press served to bring on the next stimulus (after a 100msec. delay) with the sequence of lights being generated by a software random number generator.

Subjects were assigned to loud or soft conditions at random. A ten-minute practice session was followed by individual knowledge of results. Subjects were required to work as quickly and as accurately as possible until told to stop.

RESULTS

Correct Responses.

Although the number of correct responses was numerically higher in loud noise over the four ten-minute periods of test, the overall effect of noise intensity was not significant (see Table 1).

Table 1: Number of correct responses in each task quarter for Loud and Soft noise.

	Quarters 1	2	3	4
Loud	787.0	787.7	793.0	773.2
Soft	761.7	762.6	762.9	780.7

Gaps.

Responses in excess of 1.5sec. were regarded as gaps (see Table 2). There were relatively few gaps and although there was the usual increase in their number over the period of test ($F=13.50$; $df=3,102$; $p<0.01$), the most marked increase being in the fourth quarter of the test, this could be due either to the change to silence or to the fact that the silent period signalled that the end of the test was near, the so-called 'end-effect'. However, there was no effect of noise.

Table 2: Number of gaps in each task quarter for Loud and Soft noise.

	Quarters 1	2	3	4
Loud	0.67	1.00	1.67	4.06
Soft	0.94	1.44	2.61	3.61

Errors.

Errors (see Table 3) showed a significant rise over the whole period of test in loud noise ($T=20$; $n=16$; $p<0.01$) but the rise in errors in soft noise was small and clearly non-significant ($T=53$; $n=16$; $p>0.05$). A similar comparison between the first and third quarters of the task (those periods over which there were differences in noise level) again showed that the rise was significant for loud noise ($T=18.5$; $n=15$; $p<0.02$) but not for soft noise ($T=40.5$; $n=15$; $p>0.05$). Although errors increase from the third to fourth quarter, giving some evidence of an after-effect, this was only significant with a one-tailed test (Loud: $T=33.5$; $p<0.04$. Soft: $T=35.0$; $p<0.05$).

Table 3: Errors over task quarters in Loud and Soft noise.

	Quarters 1	2	3	4
Loud	14.9	20.5	27.2	30.3
Soft	13.8	14.5	15.8	18.5

We now turn to a qualitative examination of errors. Loud noise appears to increase the proportion of fast errors. This is shown in the distributions of response times where the probability of an error is expressed as a proportion of all responses at each cell of 50msec. (see Figure 1). In the first quarter the proportions of errors are roughly similar but by the third quarter, and particularly at speeds of response below 300msec., the incidence of errors is higher in conditions of loud noise.

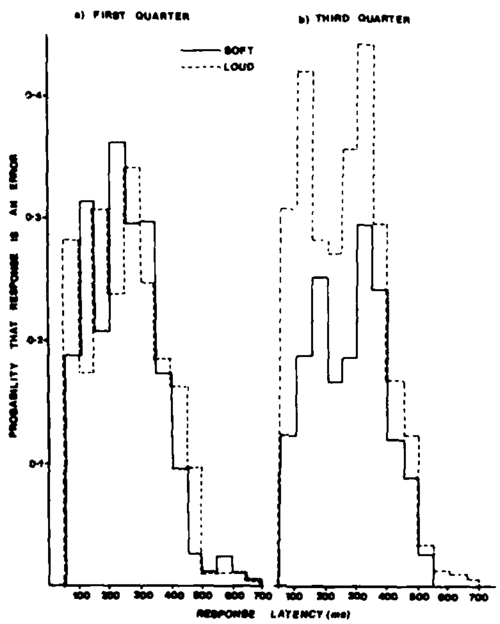

Fig. 1 - Error latencies expressed as a proportion of all responses in the first and third quarters of the task in Loud and Soft noise.

The speed of responses before and after an error are shown in Figure 2. There is some evidence of speeding up before an error with the error being much faster than the surrounding correct responses. The speed of response is markedly diminished in the period following an error: this effect extending over some three or four responses early in the period of work but being very marked only for the response immediately following the error toward the end of the task. The level of noise failed to have any significant effect on any of these trends.

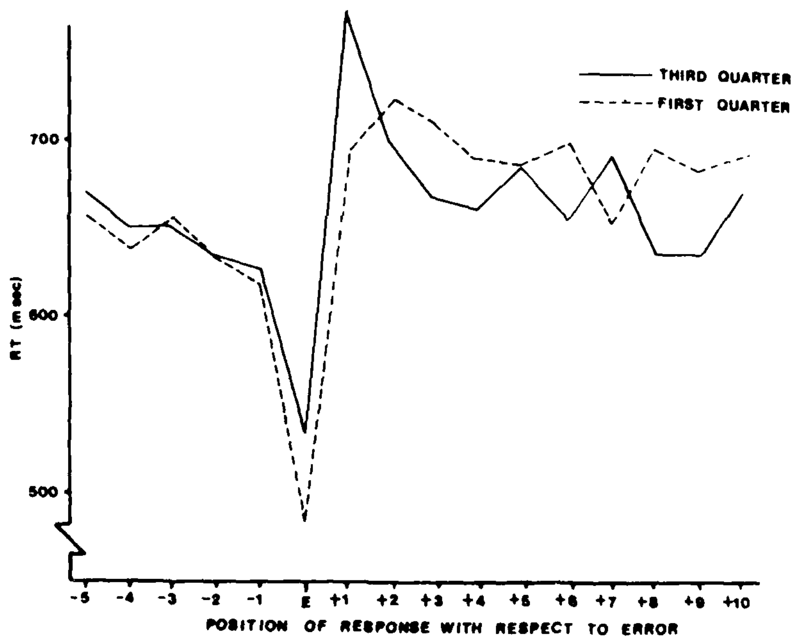

Fig. 2 - Speed of responses leading up to and following an error in the first and third quarters in Loud noise.

There was little evidence of a systematic effect of noise on the key to which the error was made. In this case interest focuses on the incidence of errors which were remote from the correct key (that is, on

a key more than one finger's distance from the correct response). When expressed as a percentage of the total errors there were no significant effects (see Table 4).

Table 4: 'Remote' errors in Loud and Soft conditions, expressed as a percentage of total errors.

	Quarters 1	2	3	4
Loud	16.14	23.87	17.87	21.41
Soft	13.07	12.43	19.39	21.79

CONCLUSIONS

By showing a significant rise in the number of errors over the period of work in loud noise these findings have cast doubt on the assertion that the effects are due to a combination of masking and arousal effects of the type proposed by Poulton. Features of the data do not lend support to the idea of an initial arousing effect of noise followed by a gradual decline in arousal, culminating in a sharp drop in arousal when the noise is switched off. However, the findings do not lend themselves to any other unambiguous interpretation. One possibility is that noise serves to increase arousal and that this effect slowly accumulates during the course of the task. Yet, such a proposal fails to furnish exact predictions about the way in which the deterioration in performance should occur.

Given that noise has only a modest effect in increasing the speed of response as shown by the probability distributions for correct and incorrect responses but that it increases the likelihood that a fast response will be an error, two explanations are suggested. The first is that noise impairs the intake of information. Let us assume that the subject attempts to maintain the same overall distribution of responses throughout the period of test. Any disruption to the intake of

information is thus likely to erode the basis on which responses are made. Responses, in order to fit into the confines of the distribution, will be based on less evidence that was hitherto available. This shortage of evidence will have particularly dire consequences for those responses that are fast and it becomes more likely that they will be errors. Problematic for this view is why the distribution of response times should remain stable, particularly in view of the possibility of adjusting the distribution to reduce the number of errors at the expense of increasing overall response times. An alternative view is that noise somehow alters the placing of the criterion or the boundary that separates correct from incorrect responses. It may be, for example, that the marginal increase in overall speed of correct responses in noise could only be achieved at the expense of relaxing this criterion. *Note, however,* that it is the proportion of errors which is increased, regardless of the absolute number of fast responses, so that noise increases the number of responses that are 'converted' to errors.

These explanations share a similar stumbling block. Noise does not have a clear effect on the speed of responses leading to and following an error. In particular the response following an error exhibits a temporary slowing, a sign of the process of recognizing that an error has occurred. Those explanations relying on some impairment by noise of the intake of information should, unless modified, predict that noticing that an error has occurred should be impaired in the same way that selection of the appropriate stimulus is impaired. Criterion shifts suffer a similar fate: the rate at which the speed of response returns to normal in the five or so responses following an error is

most likely to show a speeding in loud noise as the result of a relaxation in criterion (see Laming, 1979).

In sum, we can only offer an equivocal account of the processes governing the effect of noise on serial reaction. However, some explanations can be shown to be untenable. It is likely that further fine-grained analyses of task performance will illuminate the complex control processes which govern task performance. This quest may contribute to our general understanding of the effects of noise on performance since these seem to be in large part governed by high-level control processes which give rise to effects of the strategic type (see Jones, 1983 for a general overview).

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COMBINED EFFECTS OF BROADBAND NOISE AND COMPLEX WAVEFORM VIBRATION ON COGNITIVE PERFORMANCE

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INTRODUCTION

In our Laboratory, both subtractive and additive effects have been obtained from studies on the combined effects of noise and vibration on tracking performance, depending on the intensity level of noise used in the experiment. When noise of 100-105 dBA was combined with vibration, a less adverse effect was obtained than with vibration acting alone (2,3,18). However, when noise of 110 dBA was combined with vibration, the effects were greater than the effects of either of these stressors acting individually (4,6). The generality of these results is supported in that the effects were obtained across a rather wide range of vibration intensities (0.10-0.30 G_z (peak) at 5 or 6 Hz) and durations of exposure (19 min-2.5 h). The finding that noise, depending on its level, can either accentuate or ameliorate the effects of vibration suggests that some of the effect of vibration on tracking performance, in addition to purely mechanical interference, may be related to cognitive factors. However, the combined effects of noise and vibration on cognitive or intellectual tasks are not clear. Harris and Sommer (5) found either 100 dBA or 110 dBA noise combined with vibration produced more adverse effects on a mental arithmetic task than either stressor acting alone. The difference between conditions was small, even though statistically significant, and an attempt at replication yielded unclear results. Nevertheless, the results agreed with some previously obtained by Huddleston (9,10), who found an adverse effect of vibration on a task involving mental addition and recent memory. Other investigators, however, found no appreciable effects of vibration on various cognitive tasks (2,16,17).

In the present study, we have extended our previous research on the combined effects of noise and vibration on human performance by using a cognitive task that holds more promise for showing sensitivity to stress, and by using complex waveform vibration, which is more like operational environments than sinusoidal vibration. The task is a version of the Complex Counting Task (CCT) originally used by Jerison

(11-13) to study the effect of noise on performance and, more recently, used by Kennedy (14,15) in vigilance research. The task seems likely to be more sensitive to stress than cognitive tasks we have used in the past because it requires the continual attention of the subject and is experimenter paced. Broadbent (1) has pointed out that many failures to show adverse effects of noise on human performance may have occurred because the investigators used tasks without such characteristics.

The purpose of the present study was to determine the single and combined effects of 100 dBA broadband noise and complex waveform vertical vibration on cognitive performance. To this end, the same subjects were tested on the CCT during exposure to 65 dBA and 100 dBA noise, both with and without vibration.

METHODS AND MATERIALS

Subjects: Twelve male Air Force military personnel, who were volunteer members of the AMRL Vibration Panel, served as subjects. They ranged in age from 23-40 years. They had undergone extensive physical examination to qualify them for participation in vibration experiments and received incentive pay for serving on the panel. The hearing of all subjects was measured in the frequency range of 500-6000 Hz before and after the experiment by standard audiometric methods.

Test Facility: The vibration was produced by an Unholtz-Dickie electromagnetic shaker (Model MA 250D). Subjects sat in an unpadded rigid aluminum seat mounted on top of the shake table. They were restrained by a lap belt and shoulder harness. On all vibration runs, the acceleration level was monitored continuously from a linear accelerometer attached to the table. The accelerometer readings were amplified and passed to a strip chart recorder, and a true R.M.S. meter. Before every run, the acceleration level for each of the five sinusoids of 2.6, 4.1, 6.3, 10, and 16 Hz was set at the ISO 1-h Fatigue-Decreased Proficiency level. All five frequencies were then combined to produce a quasi-random sum-of-sines vibration, which had an acceleration level of 0.36 R.M.S. G_z.

The noise exposure was produced by a Grason-Stadler type 1285 white-noise generator, amplified by a Grason-Stadler amplifier type 1288, attenuated by a Grason-Stadler 1293 attenuator, and passed bilaterally to TDH-39 headphones worn by the subjects. The noise spectrum measured under the headphones was flat from 2500-6500 Hz and dropped off 5 dB per octave below 2500 Hz and 20 dB per octave above 6500 Hz. Noise levels of 65 dBA and 100 dBA were used.

Task: The Complex Counting Task (CCT) was used for measuring performance. On the subject's console there were three small lights mounted on a vertical panel, and three buttons on a horizontal panel. Each of the lights flashed at a different rate. The light on the subject's left flashed once every 13 s, the middle one every 5 s, and the one on the right flashed every 9 s. The task was to keep a simultaneous count of the number of flashes of each light. The subject was instructed to press each light's button every sixth time the light flashed. On an experimenter's panel located in an adjacent room, separate measures were obtained for subject's responses to each light. For each light, scores for total responses, early responses, and late responses were obtained. An early response occurred when the subject responded before a light flashed six times, and a late response anytime the subject responded after a light flashed more than six times. A

percent correct score for each light was calculated for three 10-min trials during the 30-min experimental testing period for each subject. These scores were used for statistical analyses.

Procedure: Upon arrival at the laboratory the subjects were told about the general nature of the experiment, and informed about the amount of time that would be required. They were then given training on the CCT and instructed to keep alert, to maintain an independent count of the number of times each light flashed, and to push the appropriate button after each light had flashed six times. The instructions were patterned after those used previously (7,11).

Testing for each subject was conducted during six different sessions, two practice sessions, and four experimental sessions. All testing for each subject was completed within a 2-week interval, with a minimum of 48 h between sessions. During the two practice sessions, the subject performed on the CCT in the same manner he was to perform later

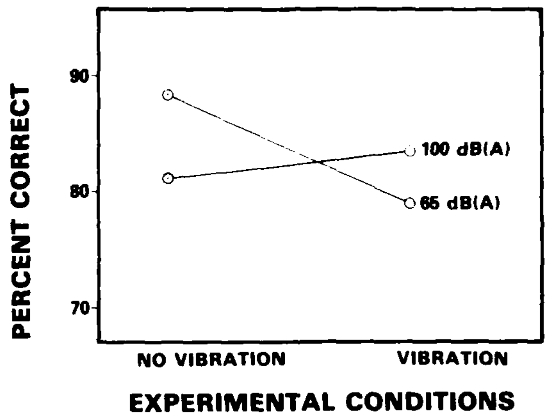

Fig. 1. Percent correct on complex counting task at no vibration and complex waveform vibration with both noise levels.

during the experimental sessions. On each test day, the subject was given a 5-min warmup trial, and then tested continuously for 30-min under one of the four experimental conditions. Subjects were informed of their scores on the task at the end of the 5-min warmup and at the end of the 30-min test session. The experimental conditions were 1) no vibration, 65 dBA broadband noise, 2) no vibration, 100 dBA broadband noise, 3) 0.36 R.M.S. G_z sum-of-sine vibration, 65 dBA noise, and 4) 0.36 R.M.S. G_z sum-of-sine vibration, 100 dBA noise. Each subject was administered the experimental conditions in a different random order. The vibratory and noise stimuli were presented continuously during the experimental conditions in which they were used.

RESULTS AND DISCUSSION

A four-way Analysis of Variance (ANOVA), based on a repeated measurement design, was calculated on the performance scores. The main

variables and their interactions examined in the ANOVA were Noise (N), Vibration (V), Lights (L), and Trials (T). Statistically significant effects were obtained for Lights ($F(2,22) = 5.58$, $p<0.025$), Trials ($F(2,22) = 5.50$, $p<0.025$), and the N x V interaction ($F(1,11) = 10.36$, $p<0.01$).

The most interesting effect is the N x V interaction. Fig. 1 shows that the effect of noise was reversed as a function of vibration. When there was no vibration, the 100 dBA noise produced poorer performance on the CCT than 65 dBA noise; when vibration was present, performance was worse with 65 dBA noise. Table I gives the results of t tests for all possible differences between the means of the four experimental conditions. These tests indicated that both the 100 dBA noise and the combination of 65 dBA noise and vibration produced significantly poorer performance than the control condition (65 dBA noise alone). This result is similar to those of our previous studies using tracking performance. In all studies, the adverse effects of vibration were

TABLE I. RESULTS OF T-TESTS FOR DIFFERENCES BETWEEN MEANS OF EXPERIMENTAL CONDITIONS.

Experimental Conditions		(1) 65 dBA	(2) 100 dBA + Vib.	(3) 100 dBA	(4) 65 dBA + Vib.
Ordered Means (Percent Correct)		88.1	83.1	80.9	78.8
Differences	(1)		5.0	7.2*	9.3**
Between	(2)			2.2	4.3
Means	(3)				2.1

* $p<0.05$
** $p<0.01$

less when it was combined with 100 dBA noise than with 65 dBA noise. However, two effects were demonstrated that had not been obtained previously. First, an adverse effect of 110 dBA noise on the counting task was obtained. Previously, a 100 dBA noise was required to adversely affect tracing performance. Second, a clearcut adverse effect of vibration on a cognitive task was demonstrated-vibration plus 65 dBA produced an adverse effect. This finding is contrary to most of the previous studies on the effects of vibration on cognitive performance. The reason may be that a more sensitive task was used for measuring performance and/or that complex waveform vibration was used in the present study instead of the sinusoidal vibration used in most previous studied.

There was also a significant effect for lights. The mean for light 3 (9-s rate) was significantly smaller ($p<0.05$) than the means for lights 1 (13-s rate) and 2 (5-s rate). This is the same result obtained in a previous study where the CCT was used to evaluate the effects of infrasound (7). In both studies, performance on light 3 was poorer than performance on the other two lights.

The trials effect indicates that performance deteriorated as a function of time. Performance on trial 3 was significantly poorer than performance on trial 1 ($p<0.05$). Fig. 2 depicts the interaction of vibration with trials. Although this interaction was not statistically significant ($p<0.10$), the trend of the data suggests that, had testing continued for a longer period of time, the trials effect would have been significantly greater when vibration was present than when it was not. This is an interesting possibility since the ISO standard for vibration exposure (8) assumes that the performance effects of vibration intensify as a function of duration of exposure, but there is little evidence to support this assumption.

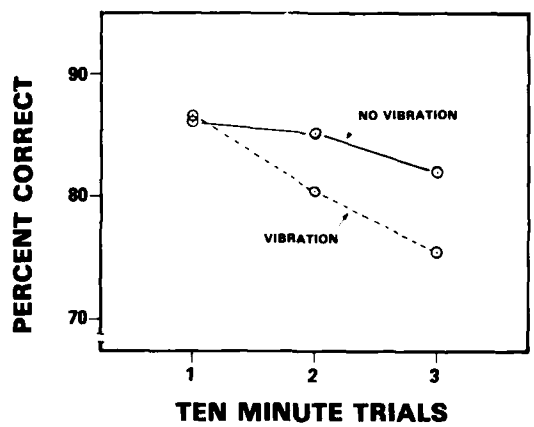

Fig. 2. Percent correct for vibration and no-vibration conditions for 10-min trials.

SUMMARY AND CONCLUSIONS

The performance of 12 subjects was measured on a Complex Counting Task during exposure to each of four experimental conditions for a duration of 30 min. Two levels of noise, 65 dBA and 100 dBA, were presented both with and without 0.36 R.M.S. G_z sum-of-sines vibration. Combined 100 dBA noise and vibration produced less adverse effects than the vibration combined with 65 dBA noise. This result agrees with our previous studies using tracking tasks. However, two effects were demonstrated that had not been obtained previously. First, a clearcut adverse effect of vibration on the Counting Task was obtained. Second, an adverse effect of 100 dBA noise on the counting task was demonstrated. Previously, a 110 dBA noise was required to adversely affect tracking performance.

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TASK TYPE, TYPE A AND B AND SENSITIVITY TO NOISE

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INTRODUCTION

Any environmental event, be it physical (e.g. noise, heat) or psychological (e.g. emotion) is capable of eliciting a stress reaction, depending on the subject's appraisal of its potential threat (Lazarus 1966, Class & Singer 1972, Cohen 1981). Knowing how we select, interpret and judge information is a prerequisite to understanding the effect this input has on us (Moch 1981, 1982). Studies of differential sensitivity to noise stress as a function of personality differences are still contradictory and cannot be compared due to the lack of standard measurements (Levy-Leboyer 1975).

Among the many personality factors which mediate the relationship between the individual and his environment, we have chosen to study the behavioral patterns called type A and type B. Type A, described for the first time in 1959 by Friedman and Rosenman, is characterized by high-pressure, competitive, driven behavior, and is considered to be related to premature atherosclerotic heart disease (coronary-prone behavior). Pattern B is characterized by the relative absence of these traits. Types A and B are the extremes of a bipolar continuum on which any

person could be located.

Some studies have found differential physiological, behavioral and cognitive reactions to stress as a function of the A/B pattern type. Pittner & Houston (1980) found that type A and B subjects show cognitive differences in their way of coping with stress in the form of a threat to self-esteem or threat of electric shock. Type A subjects avoid thinking about the stress, deny the threat and report less subjective stress, although they manifest more psychophysiological arousal.

A study by Carver, Coleman & Glass (1976) showed that type A individuals exert greater effort on a treadmill exercise test than do type B, and report significantly less overall fatigue. A study by Glass (1977) showed that type A individuals deny the aversiveness of noise.

The present study examined sensitivity to noise in type A and B behavior patterns as a function of the type of task. We hypothesized that type B subjects' evaluation of the aversiveness of noise would be more related to task complexity than would type As'.

MATERIAL AND METHODS

I. Subjects

We randomly selected by Bortner's French version scale (1969) 20 female undergraduates at the University of Paris VIII who scored in the bottom quarter of a pretest distribution as being type B (low scores indicate type B behavior) and 20 who scored in the top quarter of the distribution as being type A.

The scale's validity and reliability have been demonstrated by several European research teams (Defourny, Frankignoul 1976 ; Pichot, de Bonis, et al 1977). This scale consists of 14 items. The subject rates himself on each item (a bipolar continuum) on a scale from 1 to 24. His total score is the sum of his 14 self-ratings.

II. Procedure

Subjects were individually exposed to a high frequency (3000 Hz)

tone presented through Sony DR S3 earphones which have been calibrated by a Bruel & Kjaer noise analyzer with an artificial ear. The noise increases about 6 DbA every twenty seconds until it reaches 110 DbA.

Each subject carried out two tasks. The first consisted in crossing out those signs, among many others, which matched a model (Zazzo cross-out test). The second consisted in writing down all the nonsense syllables recalled after one presentation of a list of 20.

The subjects were told they might hear noise through the earphones. They were instructed to signal if the noise disturbed their work.

RESULTS

Responses (indication that the noise was disturbing) were scored on a scale from 1 to 8. "One" represented disturbance indicated at 68 DbA and "eight", at 110 DbA. If the subject made no response, the maximum score (high tolerance) was given. Table 1 gives the means of sensitivity to noise.

	TASK I	TASK II
TYPE A	$M_I A = 6{,}35$	$M_2 A = 6{,}40$
TYPE B	$M_I B = 6{,}30$	$M_2 B = 5{,}40$

Table 1 - Means of sensitivity to noise.

If we illustrate this result we obtain table 2.

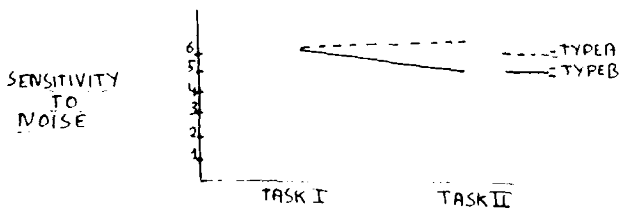

Table 2 - Means of sensitivity to noise as a function of task type and behavior pattern (A/B).

It can be seen on the graph above that there is a differential effect as a function of the A/B dimension.

Means of the two groups are very similar in the first test, $m_1A = 6.35$, $m_1B = 6.30$ (F = ns), while they differ in the second test $m_2A = 6.40$, $m_2B = 6.30$ ($F(1,38) = 4.78$ $p < .05$). Type A subjects consistently maintain their level of tolerance. On the other hand, type B lower theirs in the memorization task, $F(1,19) = 11.11$ $p < .01$.

The analysis of variance of sensitivity to noise revealed a significant main effect for type of task, $F(1,38) = 7.90$ $p < .01$. There is not a significant main effect for the A/B dimension, $F(1,38) = 1.55$ ns. The interaction of A/B and task, however, is significant, $F(1,38) = 9.86$ $p < .01$.

Table 3 gives the number of subjects who maintain, increase or lower their sensitivity to noise.

TYPE / SENSITIVITY	=	↗	↘
A	13	4	3
B	6	2	12

Table 3 - Number of subjects who maintain, increase or lower thier sensitivity to noise

A post-experimental rating of three noises (low, medium, high) on a seven point scale showed that noise intensities were clearly differenciated for all subjects, $F(2,36) = 267.49$ $p < .001$.

There is not a significant main effect for the A/B dimension, $F(1.38) = 0.54$ ns. The interaction of A/B dimension and noise intensi-

ties is not significant, $F(2,76) = 0.14$ ns.

DISCUSSION

Results of previous studies of the effect of noise on performance often differ, but they agree on the fact that simple, repetitive tasks (like crossing-out) are generally unaffected by noise. More complex ones, such as intersensory integration and cognitive tasks like mental arithmetic and problem solving, are often detrimentally affected (Cohen 1980). Memorizing is also said to be highly affected by noise, the main effect occurring in input processing and storage (Wittersheim, Salame, Spence 1977).

The results of this study show that subjects working on a task react differently to noise. Type A subjects maintain their noise tolerance regardless of task, while type B subjects are more sensitive in a complex one, being aware of the disturbing effect of noise on memorizing.

Since the two types do not differ in their capacity to evaluate noise intensity, differences can be explained by their responses to the environment while carrying out a task of high complexity.

The results confirm the hypothesis that behavior patterns A and B mediate subjects' dealing with environmental input such as noise.

Type A subjects, characterized by intense achievement striving, have a greater investment in their work. This often shows up in an increase in physiological measures of autonomic activity, such as blood pressure, heart rate and cholesterol serum (Goldband 1980, Lovallo & Pishkin 1980, Carver, Coleman & Glass 1980) although their level of

performance is not necessarily improved.

However, it is difficult to know whether, due to this greater investment, they pay less attention to noise in the complex task, [illegible] cognitive mechanisms to deny the aversiveness of the noise and thereby experience less subjective distress.

Type A subjects appear to overadapt to the aversive aspects of the environment. In this study some subjects stood intense noise without comment or complaint. We may well question the cost to the individual of such adaptation, and the potential risks, such as cardiovascular disease, which it entails. The type A pattern is a mode which is damaging to physical and mental health, because of the cumulative effects of repeated efforts to overadapt to stress.

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STUDYING THE AFTER-EFFECTS OF NOISE ON REACTION TIME BY APPLICATION OF VARIOUS MODELS OF TIME SERIES ANALYSIS

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INTRODUCTION

Changes in performance due to noise disturbance are the most controversial topics in the field of research on noise effects (BROADBENT 1979; BURNS 1973; GULIAN 1973; KRYTER 1970; MILLER 1974; POULTON 1979). The relevant scientific literature presents the following findings: There are studies which prove that performance increases under the influence of noise and those which maintain just the contrary. Others could not find any effect on performance at all (summarized by LOEB 1980). Completely non-transparent are the so-called after-effects, that means noise may produce performance alterations not only during exposure, but may occur after its termination (GLASS & SINGER 1972; COHEN et al. 1973). A possible explanation of this problem may be the different use of the term performance: The most varied forms of reactions (e.g. control activity, opportunity to choose, rapidity of reaction, learning achievement, memory training etc.) are all included among performance. Usually they are measured with regard to their quantity (e.g. volume, speed) and/or their quality (e.g. grade, accuracy, frequency of errors.) Especially when investigating performance alterations after sleep disturbances caused by noise, accuracy and speed tests were used (WILKINSON 1968, 1970; WILKINSON et al. 1980). WILKINSON (1969) has pointed out, that

the w a y in which a stress factor affects performance merits more attention. Therefore our main interest was not to study the absolute speed or accuracy of performance but we tried to examine a further aspect: The rhythmicity, i.e. the steadiness of performance over a certain time period.

MATERIAL AND METHODS

The experiments have been carried out on 20 subjects. To study the influence of noise disturbed sleep on people's performance the next day, four-choice reaction time tests (see WILKINSON & HOUGHTON 1975) were recorded during 12 mornings in the subjects' homes. The experimental scheme followed an A-B-A design (control-experiment-control). The experimental condition consisted in wearing earplugs or opening the windows. The average difference between the "noise" and "quiet" condition was about 10 dB(A). All subjects slept under both noisy and quiet conditions during 12 consecutive nights each. The experimental condition was executed during the 6th to the 10th night. The individual differences in performance rhythmicity should be tested between noise and quiet conditions. Because of eliminating practicing effects (WILKINSON et al. 1980), we did not examine average reaction time by arithmetic means but we tried application of time series analysis (JENKINS 1979; KENDALL 1973).

Time series analysis is an often used method for analyzing data, which occur sequentially in time. Applications can be found in a wide variety of fields like economics, social science, engeneering, physical and biological sciences. There are two approaches to time series analysis, a frequency domain (or spectral) approach and a time domain approach. In the second case the main point of interest is to find an explicit parametric model for describing the data. Among these models are for instance the well-known autoregressive and moving average models (BOX & JENKINS 1976). Applications are control and fore-

casting of time series. In the frequency domain approach it is assumed that each frequency (period) within a given range contributes to some extent to the oscillatory variation of the data over time (CHATFIELD 1980). The spectral density function shows the distribution of the variance of the data over different frequency bands and allows to detect cyclic components in the data.

In an earlier study (JANSEN 1980) we used the frequency domain approach to analyse physiological data, which have been taken over a period of 45 minutes without and with direct noise exposure to the subjects. The results of this study enforced us to applicate this method to the reaction time data described above.

There are two main problems to solve: The first problem is to examine if there are regular oscillations (rhythmicities) in the reaction time data by estimating the spectral density function; a so-called spectral analysis has to be done. If such rhythmicities can be detected, the second problem is to study the variation of the spectral density function paying a special attention to the different experimental conditions. But before starting this research, some assumptions have to be fulfilled for the application of spectral analysis. In the first place the analysis is based on equally-spaced data in the time domain. Because the reaction-time data does not follow this assumption, a data transformation has been necessary. We chose a simple piecewise linear approximation and than computed the new values at constant time intervals, namely the arithmetic means (Fig. 1). This implies, that an existing individual rhythmic component is not affected by the transformation.

Secondly, a time series should be stationary, that means that the statistical properties of the time series are independent of the time. If there is a trend in the data, it is to be removed before performing spectral analysis. In order to avoid the problem of practicing effect, a linear trend

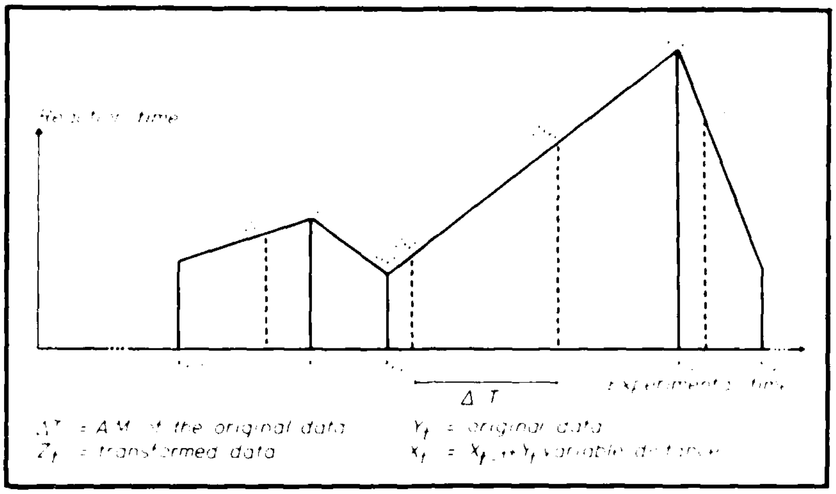

Fig. 1 - Transformation of reaction time data to equally-spaced data.

with least squares criterion has been computed for each of the 20 x 12 trials and afterwards the residuals have been taken for the further analysis. The main feature of the spectral analysis is estimating the spectral density function. A plot of this function is called the (power) spectrum. An example for such a spectrum is shown in Fig. 2.

The computation of the spectrum is done in three steps:

1) Shift the time series stepwise until the so-called truncation point is reached and compute in each step (lag) the autocovariance function.
2) Weight the truncated autocovariance function by a so-called lag window, in order to get a consistent estimation of the spectral density function.
3) Transform the truncated and weighted autocovariance function from the time domain to the frequency domain by computing the spectrum.

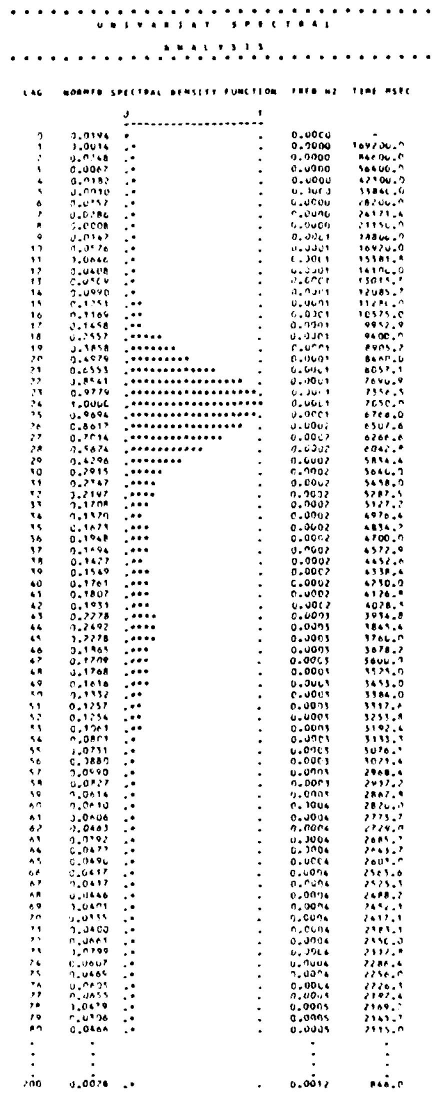

Fig. 2 - Plot of a spectrum of reaction time data (subject 1, trial 2)

Because of the fact, that there exists no fixed rule for the determination of the truncation point and that different lag windows can be selected, several models have been tried. For the final computation of the spectra of all trials we chose the Parzen Window and a truncation point of 200 lags.

RESULTS

The following variables have been derived from the spectra:

- lag (SP1) and period of oscillation (SP2, in seconds) corresponding to the maximal peak,
- width of the maximal peak with regard to the value of 0.5 in the normed spectrum (SP3), measured in number of lags,
- number of lags with the normal spectral density function greater 0.5 (SP4),
- SP5 = 100 x SP3/SP4,
- SP6 = 100 x SP3/201.

The value of 0.5 has been chosen in the spectrum to avoid interpretations of stochastic components. Because of the different time intervals in the trials, the estimated spectral density function has been evaluated at the points $w_l = \pi \times l/200$ ($l=0,1,\ldots, 200$), whereby w_l is measured in radians per unit time and l is the value of the corresponding lag. From this it follows that the spectra can be compared with each other. The width of the maximal peak gives an idea, how good the main oscillation is seperated from neighboured oscillations. The last two variables indicate the power of the main oscillation. Table 1 gives some basic statistics of the spectrum variables.

Table 1: Basic statistics for the spectrum variables

	AM	Median	SD
SP1	26.2	25.5	5.9
SP2	6.6	6.3	1.8
SP3	15.1	15.3	5.6
SP4	20.5	19.6	7.1
SP5	76.7	81.3	21.4
SP6	7.6	7.6	2.8

Obviously the results show the existence of a main oscillation in all trials. The lag of the main oscillation is concentrated at lower values with a corresponding period of oscillation of 6.6 seconds on the average, which implies a mean number of 16 reactions per oscillation. By the inspection of the plots of the spectra and the results for the variables SP5 and SP6 follows, that the total power of the spectra is concentrated at the main oscillation and the spectra are tending to zero with increasing lag. This fact suggest that there is no aliasing effect (LEINER 1978) and that the determination of the time intervals has been in the right order of magnitude.

The second aspect to be taken into consideration was to analyse the problem, if there are any changes in the spectrum variables under different experimental conditions. Table 2 shows the AM of the spectrum variables with regard to subgroups and conditions.

Table 2: AM of the spectrum variables corresponding to experimental conditions

Earplugs group

	Noise	Quiet	Noise
SP1	26.3	26.5	26.4
SP3	15.4	15.4	13.6
SP5	81.6	72.4	73.7
SP6	7.6	7.7	7.4

Window group

	Quiet	Noise	Quiet
SP1	26.4	25.5	25.0
SP3	13.9	15.8	17.0
SP5	73.1	76.8	87.6
SP6	6.9	7.9	8.6

Test statistics have been computed with the result, that

no significant differences either between the groups nor between the conditions within the groups could be established. An interpretation of this results could be, that under the aspect of studying after-effects of noise, the duration of the trials should be extended (in any case more than 10 minutes per trial).

CONCLUSIONS

Our results suggest, that time series analysis is a useful method for the examination of reaction time data. The existence of a stable rhythmic component could be demonstrated. Studying the after-effects of noise on the derived variables of the spectral analysis shows no significant changes in the variables with regard to different experimental conditions. This result leads to the assumption that the rhythmicities are not affected by short trials because of their stability. Therefore the duration of the trials should be extended when studying after-effects of noise. Furthermore it seems to be useful to study direct-effects of noise on reaction time with the help of time series analysis.

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PROPOSAL FOR A SCIENTIFIC PROGRAM

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In the last two reviews on noise and performance Gulian (1975) and Loeb (1980) have remarked, sadly, that despite a great number of studies very little progress has been achieved *in understanding* the effects of noise on human behaviour. It is, therefore, gratifying to be able to say, at last, that the situation appears to be slowly changing. As was shown in Broadbent's review and in the papers presented in our session we are beginning to form a clearer picture of the intervening factors which account for the human behaviour in response to noise. The reason for this lies primarily, we think, in a change of emphasis in noise research. Until the *mid-seventies* the bulk of research was on the effects of noise on perceptual-motor skills, and the main variables taken into consideration were the physical characteristics of noise. Currently, research on noise, following the overall trend in psychology, has become cognitive-oriented. Attention has been focused on the way in which many cognitive activities mediate the effects noise has on performance as well as on the strategies people employ in coping with noise.

Much work is still to be done and the discussions of our team about

priorities in future activities have highlighted the following main areas: (I) development of a broad theoretical approach to research on noise and behaviour; (II) determining the underlying cognitive processes of performance tasks; (III) elucidating the role of the meaning of noise, and of (IV) coping strategies in determining noise effects on behaviour, and (V) collecting data to establish a broader range of generality across both environment and populations.

Theoretical Development

There is a need for an integrated multiple theory approach to understanding the effects of noise on performance. It is recognized that noise may affect performance in a number of ways including masking important performance cues, modifying the level of arousal, influencing information processing strategies, and altering feelings of helplessness, affect and motivation. The principle question now is how do these different components interrelate theoretically? We need to identify which theories focus on independent processes and which overlap. We also need to establish criteria for understanding when each theory applies and how the theories interact with one another when multiple theories apply in the same situation. Such an integration of theoretical approaches would allow for a more accurate prediction of the effects of noise on performance across situations.

Task Characteristics

We need to develop a taxonomy of tasks based on the cognitive processes that underly their performance and to choose our experimental tasks based on this taxonomy. Recent work suggests that many noise effects on performance can best be understood in terms of the specific processes that are either interfered with by noise or are apparently unaffected by noise. A taxonomy would allow existing tasks to be

classified according to their similarities and differences in required information processing. This approach suggests that future work may be most useful to the extent that it manipulates and/or assesses the processes involved in experimental tasks. The development of a taxonomy of tasks can be aided by recent work in cognitive psychology on distinguishing various processes in task performance.

Emphasis on Meaning

More emphasis should be placed on the meaning of the noise for the exposed person. The meaning of a sound is influenced by the social and physical context in which it occurs and by individual differences in coping and personality. Context issues are of special import in performance experiments and have received little attention up to now. For example, the experimenter's dress and demeanor, the exact instructions given to the subject, and the physical layout of the laboratory may have important implications for subjects' interpretation of loud disruptive sound. Studies manipulating context and noise independently and determining how noise and context interact to affect performance would be a welcome addition. At a different level, comparisons of the predictive validity of self-reported threat and annoyance with sound level, and other physical parameters of the noise would provide a first approximation of the role of meaning in the relationship between noise and behaviour. However, even this step is a difficult one in that it requires the use of psychometrically valid measurement instruments for assessing self-reported levels of stress.

A closely related issue is the determination of the information content of a noise stimulus. Information content of the sound may similarly play an important role in determining the meaning of the noise

for the respondent and hence its impact on behaviour.

Coping Strategies

The purposive strategy for coping [illegible] that a subject uses [illegible] with noise while performing a task is [illegible] a central mediator of [illegible] effects of noise on behaviour. It is proposed that future research [illegible] manipulate and measure these strategies and relate them to performance outcomes. The main directions to pursue in this area include documenting the differences between strategies used under short and long-term exposure, and under intermittent and continuous exposure.

Also of interest are the costs of pursuing particular strategies. Work on the psychological and physiological costs of coping with noise could provide evidence of noise effects that occur for those who are apparently successfully dealing with the noise, i.e. their performance is not affected. Further work on post-noise aftereffects especially as occurring in real-life settings appears to be particularly interesting.

Issue of Generality

There is a serious concern that research on noise and performance does not allow adequate generalization to the work place. This concern follows from the criticisms that research has been conducted almost entirely in laboratory settings, used a restricted range of tasks that often were not related to tasks used in real-life noise-impacted settings, and employed young, healthy adults as subjects. Future work should utilize tasks that are more representative of real-life situations, conduct field research to compliment laboratory investigations, and recruit subjects from a wide range of ages in order to cover the life span. Of special interest in this regard are the effects of noise on the performance of children and of the elderly. These two groups may be more

susceptible to noise and hence be more likely to show noise induced effects on performance.

Future research should also concentrate on the interaction between various objective and subjective factors which, presumably, interact in determining performance in real-life conditions. Among those the interactions between time-of-day, gender, task complexity, physical characteristics of noise and its meaning for the individuals exposed to it, seem the most relevant.

To summarize: we feel that further development of theory, work on the meaning of the sound rather than just its physical parameters, work on process oriented task taxonomies, and on the role of strategies adopted under noise will cumulate to provide a substantial advance in our knowledge about the effects of noise on performance. Further emphasis on expanding the generality of this research to other environments and populations will help increase its import for real-life work settings.

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Poster Session

ANNOYANCE AND ACTIVITY INTERFERENCE-OUR EXPERIENCE AT CIAL.

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INTRODUCTION

Annoyance is a subjective concept containing emotional connotations related to our total experience in noise and involves semantic difficulties. Its subjective evaluation is only possible using multifactor analysis of attitudinal scales. Its physical evaluation con only be approximated by carefully selected indices, applicable to annoyance, from long term environmental noise evaluations.

If we restrict our objective to the measurement of activity interference by noise, noise effects can be subjectivelly assessed with reasonable certainty by means of properly designed questionnaires and the respective noise sources can be measured by means of adequate units or indices, correlateable with subjective reactions.

Recent papers by K.D.Kryter and T.J.Schultz (Ref.1), preceded and followed by mutual comments and rebuttals, justify our efforts towards a clarification of this conflict. The main controversial subject is centered (see Fig. 1 of Kryter's paper) on the verbal description of annoyance. Its five degrees of annoyance are arbitrarily related to extent of the annoyance in percentages. Schultz's observation (p. 1[illegible]3, I, JASA 72 (4) october 1982): "I have tried to keep survey annoyance responses quite separate from the data on interference with specific

activities".... and later" Kryter likes to mix annoyance and interference" (Ref.2) is in our opinion the crux of long time discussions and confusions among researchers.. This confusion pervades almost every paper dealing with annoyance and its correlation with the numerous indices generated in the hope of measuring annoyance by the same figure as the effects derived from interference caused by the main types of community noise such as: safety, comfort, perfomance, relaxation, sleep, etc.

Comprehensive reviews by Schultz in the USA and Schaefer in Germany (Ref. 3) describe not less than 76 such indices, their intercorrelations as well as their correlations with subjective, objective and laboratories and field surveys.

OUR RESEARCH

We have done our own research both at the laboratory and in the field, partially reported elsewhere (Ref. 4) and our conclusions can be summarized thus: 1. Annoyance is not amenable to quantification by single factor subjective scales. The same noise may affect differently according to their attitudes. An attitudinal scale reveals the revelant opinions in a continuum These opinions refer to interfering effects on the listener. The corresponding effects depend, not only on the type of noise but on the listener, his activity and the environment in which such noise is perceived.

The scale we used was based on Thurstone's method of Successive Intervals. Thurstone defines attitude as the sum total of inclinations, feelings, prejudices, tendencies, ideas, fears and beliefs of the listener expressed as an opinion. Favourable and unfavourable reactions to environmental noise were considered (bipolar scale) obtaining 110 opinions, which were presented to 111 judges asked to place them in a continuum. Judges were asked not to express personal opinions but the degree to which the enunciations were favourable, unfavourable or neutral with respect to the noise. Median and standard deviations were computed taking $\delta_{st} \leq 1.6$.

An intercorrelation matrix of 63 items of the attitudinal

scale was treated statistically by the method of maximal likelyhood, Orthognal Varimax and Oblique Promax rotations were performed. Six factors were obtained.

In Fig. 1 we have summarized the factorial saturation of inteerfering as well as favourable effects of various environmental noises on normal indoor activities (sleep, conversation, TV., etc). We have excluded judments of annoyance.

The main object of research on interfering effects is to design environments that are acceptable for the above mentioned activities. Physical measurements (L_{eq}, L_{dn}, L_A, etc) and indices of environmental noise need only correlate roughly with the desired subjective situations. Yaniv e.a. (Ref. 11) have analysed various indices and concluded that L_{eq} shows the highest correlation with "adverse human response" to traffic noise.

In our analytic research on acoustic design of the human "habitat" with Prof. Lara Saenz of Spain we have reduced design criteria to only four situations based on functions, activities and sensitivities to noise (Fig. 2). We ignore the degree of annoyance but rather look for acceptable situations thus avoiding what we consider a superfluous precision as to whether the listener is "moderately" or "extremely" annoyed or whether "complaints" are likely to arise or not due to environmental noise.

Besides the assessment of adequate levels for sleeping, a condition only attained fully bellow 40 dB(A) at night, we have tried to determine acceptable conditions (Ref. 6) for communication in rooms, an essential parameter for good acoustical design. Conventional intelligibility tests only indicate the clarity, or "netteté" as Busnel puts it (Ref. 7), of the words in the message. What is really important is the message itself and this implies a neurophysiological operation which escapes articulation tests. Webster (Ref. 8) has related articulation to S.I.L. and L_A versus distance speaker-listener and voice effort. We have checked quality as judged by listeners for

ITEM	INTERFERENCE	FACTORIAL SATURATION
23	DIFFICULTY TO FALL ASLEEP	0,95
10	CAUSE OF INSOMNIA	0,47
46	STREET NOISE INTERFERES LISTENING TO T.V.	0,37
1	EXTERNAL NOISES INTERFERE NORMAL CONVERSATION	0,33
ITEM	FAVOURABLE NOISES	
48	CITY NOISE ENJOYABLE	0,54
3	ENJOYMENT OF MUSIC FROM NEIGHBOURS	0,34
32	ENJOY NOISE FROM STREET	0,33
25	EXTERNAL NOISE DOES NOT INTERFERE ANY TASK	0,31
17	CAN CONCENTRATE WITH EXTERNAL NOISE PRESENT	0,61
15	STREET NOISE HELPS AROUSAL	0,38
39	STREET NOISE HELPS KEEP AWAKE DURING WORK	0,36

Fig. 1 _ Bipolar Interference - Acceptability

1		2	
FUNCTIONS	ACOUSTIC RELATED ACTIVITIES	SENSITIVITY TO NOISE	CRITERIA dB(A)
INDUSTRIAL PLANTS (MACHINERY) VEHICLES (TRANSPORTATION)	COMMUNICATION AND WARNING SIGNALS	LOW	$L_{eq(8)} \leq 70$
ARTS AND CRAFTS BUSINESS AND ADMINISTRATION URBAN SERVICES SOCIAL ACTIVITIES	SIMPLE MENTAL TASKS	MEDIUM	$L_{eq(8)} \leq 50-60$
CREATIVE WORK LEARNING AND CULTURAL	COMPLEX MENTAL TASKS	HIGH	$L_{dn} \leq 40-50$
a) HEALTH CARE b) SLEEP c) SOUND RECORDING AND PLAYING	RECOVERY PERIODS LISTENING	CRITICAL	$L_{dn} \leq 40$

Fig. 2 _ Acoustic Design Criteria ——— After A LARA SAENZ and G.FUCHS

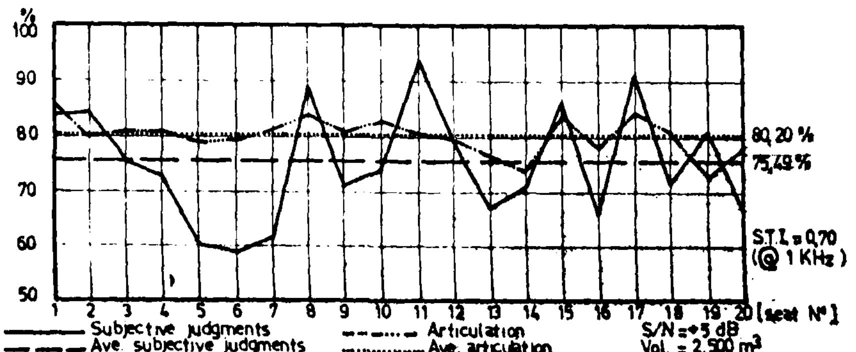

Fig. 3 Comparison of Criteria

connected speech (Ref. 8) in Spanish. The correlation of this subjective parameter to articulation is shown (Fig. 3) as well as its relation to speech transmission index S.T.I. as suggested by Houtgast and Steeneken (Ref. 9). Our judged "quality for speech" expressed as a percentage is more sensitive than articulation (phonetic tests) and very close to S.T.I., assessing acceptability of a room for communication. We presented (Fig. 3) results for and auditorium of 2500 m^3 and a rather flat T_{60}= 2 sec. S.T.I. was computed only for 500 H_z, 1KH_z and 2KH_z. Articulation and subjective quality tests were performed with 20 listeners in key positions of the room and rotated through all of them. ANSI-S. 3-5-1969 tests were not done because they are too laborius an unnnecessary for Spanish. The Spanish language requires higher percentages (above 70 % articulation) than English for acceptability bacause of its higher contents of vowels especially to end syllables, as has been revealed by a linguistic study of more than 46000 words from literary and newspaper writings analised at our laboratory.

CONCLUSIONS

- Interfering effects of intruding environmental noise is preferable and more readily related to physical measurements than the evaluation of annoyance and its correlation with levels or indices.
- Acoustical design being the goal of research on annoyance and effects of noise on people, it seems appropiate to concentrate on the latter and relate it to a few degrees of acoustic sensitivity for current indoor activities.
- Communication, one of the most critical activities in noise (besides sleep or rest, which are important but difficult to quantitate is appropiate to evaluate the contents of the message rather than its mere "netteté" or clarity. This is readily achieved by subjective quality tests for Spanish and can be objectively measured by the S.T.I. as suggested by Houtgast e.a.

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EFFECT OF NOISE ON CHILDREN AT SCHOOL

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INTRODUCTION

This research was performed to determine whether behavior of children accustomed to study in a noisy classroom would be changed if the classroom were quieter.

MATERIAL AND METHODS

We chose two school sections, a kindergarten (4-6 years) and the last primary school class (10-11 years) in each of two noisy schools, one near an airport and the other near a highway. Our multidisciplinary team included acoustical engineers, psychologists and physicians.

Children were observed for several months in their normal noisy classroom. Then insulation was added, and observations were resumed for the other half of the academic year.

I. Acoustics

1) Noise measure : Two previously calibrated LEM DO 21 microphones were set up, one outside and the other inside the classroom. The noise was recorded on a two-tracks REVOX tape recorder, either in an empty classroom or during each five minute sequence of observation.
Analysis of the tapes were made on a computer with a program of evaluation of equivalent noise levels by third octave band.

2) Insulation : A second 8 mm window pane was added to the already existant windows ; air tight joints and double doors were installed.

II. Psychological measures

1) Questionnaires concerning the children housing conditions, normal behavior, and utilization of spare time were completed by both parents and teachers.

2) Observations : Psychologists sat in a corner of the classroom and

observed the children's behavior according to previously established criteria :

a) Positive criteria : attention and active participation in classroom activities.

b) Negative criteria : all signs of distraction ; for example : chattering, play, regressive behavior (finger or pencil in the mouth), emotional behavior (crying), somatic behaviors (yawning, sigh) or fidgeting (changing position, agitation, legs rocking), making noise, etc ...
Each of the 24 children of each class was rated (1 or zero) once a minute during several five minute sequences of observation, three days a week, during the academic year. All these observations were quantified to give every child a positive or a negative index ('t' Student test) of behavior or computerized for factorial analysis.

In the kindergarten we distinguished between directed or free activities.
For elementary school, observations were performed, either during oral lessons, and/or written exercises.

III. Physical measures

Medical examinations and audiograms.

RESULTS

I. Acoustical improvement

a) Fig. 1 shows the reduced level of noise inside one of the classroom after insulation and acoustic correction.

b) Acoustic correction reduced reverberation from 2 to 1 second on the average.

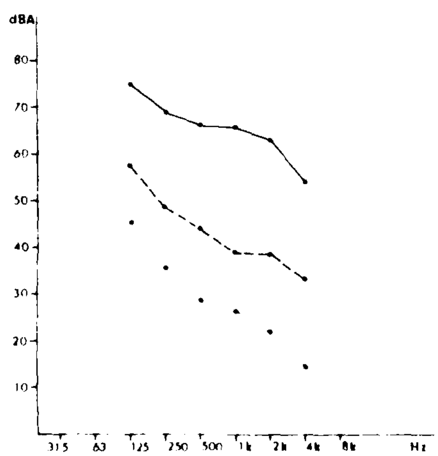


Fig. 1 Levels of noise inside and outside one empty classroom

.... inside after insulation
---- inside before insulation
—— outside

II. Psychological observations

After insulation : a) In kindergarten, during free activities only, there is an increase in positive criteria and a decrease in negative criteria (Table 1) in about 80 % of the children.

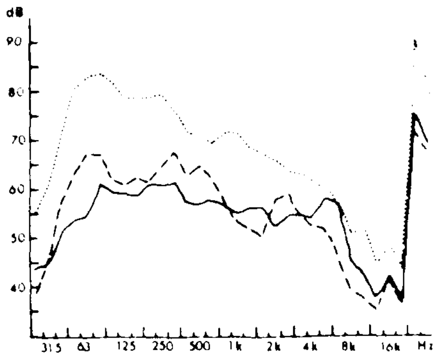
b) In elementary school children participate more to school work, were less absent minded during all activities but even more during oral course (Table 1).

Table 1 : Mean psychological scores

	before insulation	after insulation	t	[illegible]
Kindergarten (different score)				
positive criteria	0.7729+0.022	0.837 +0.0206	3.94	0.001
negative criteria	0.2393+0.0172	0.1937+0.0134	2.605	0.02
Elementary school (mean scores)	before insulation	after insulation	t	[illegible]
motor agitation	2.757+0.086	2.355+0.087	5.009	5.10^{4}
participation	2.631+0.106	3.045+0.002	5.594	5.10^{4}
noise made by the children	1.855+0.072	1.134+0.036	10.823	5.10^{4}

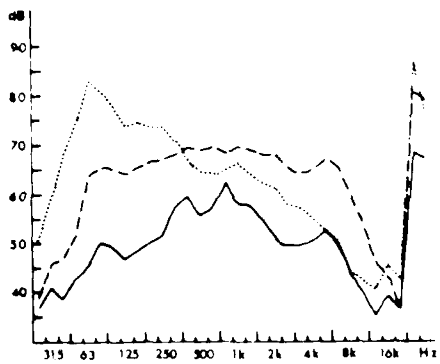
Behavior of children sitting near the window in the noisiest places in the classroom was improved by insulation more than that of children sitting far from the window indicating the real hindrance of noise.

In kindergarten, the level of the noise produced by the children's voices (high frequencies) was reduced by approximately 20 dB after insulation while it exceeded the outside noise before insulation, its level was below after insulation (Fig. 2). This appears to be due to easier social contact and less agitation. In elementary school the level of noise at all frequencies is just slightly reduced due to children's age and type of school discipline (Fig. 3)



- Fig. [illegible] : Kindergarten : levels of noise inside and outside the classroom during school work

.... outside
---- inside before insulation
inside after insulation



- [illegible]

.... outside
---- inside before insulation
inside after insulation

DISCUSSION and CONCLUSION

The behavior of children in school is greatly affected by reduction of noise in their classroom. Our hypothesis that insulation of the classroom will improve children's behavior and their social contact, whatever their age was supported. The children themselves indicated that they were more concerned by noise during school work than by noise at home and that they appreciated the insulation of their classroom. We also found that the more agitated children who lived at home in the noisiest and more crowded environments were the most improved by insulation. This shows that children living in more difficult conditions are more sensitive to environmental improvement.

EFFECTS OF NOISE AND RATE OF PRESENTATION ON REHEARSAL IN SHORT TERM SERIAL ORDER MEMORY.

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INTRODUCTION

Using a serial order recall task, Mohindra & Wilding (1983) showed that white noise did not affect the rate of overt rehearsal for visually available items but that if items had to be retrieved from memory for rehearsal, then noise slowed rehearsal. This result suggests that noise in some way interferes with the retrieval of items held in memory, either by hindering the retrieval process, or because storage of information presented in noise is impaired.

Assuming that rehearsal is a time dependent process it is likely that items presented visually at a fast presentation rate would suffer difficulty when being recoded into a phonological code required for rehearsal than if they were presented more slowly. Also in fast presentation conditions, the opportunity for rehearsal between items is likely to be reduced. However, provision of a delay prior to recall, could provide the necessary time for retrieval of phonological codes and for any subsequent rehearsal activity. We would therefore predict, that effects of noise observed at fast presentation rates probably reflect an impairment occurring at the item input stage, while effects observed at slower rates of presentation imply an impairment occurring while items are transformed from a visual to a phonological representation.

In the experiment to be described, in addition to manipulating rate of presentation, the acoustic similarity of the letters to be remembered was also varied. Murray (1965) showed that articulating items

aloud during presentation or rehearsal, particularly impairs retention of acoustically similar items. However, Wilding & Mohindra (1980), comparing effects of noise to those of overt articulation concluded that while noise improved the recall of acoustically similar items, articulation impaired it, but only at a slow rate of presentation of 2items per second.

In the present experiment presentation of items at a rate which would preclude articulation during item presentation was thus compared to slow presentation conditions. Also on some trials, a delay prior to item recall was provided for retrieval of phonological codes and to encourage rehearsal activity.

MATERIAL AND METHODS

Subjects. 20 subjects, randomly allocated to either the 65 or 85 dBC white noise conditions participated in the experiment.

Stimulus Materials and Procedure. Stimuli used consisted of 48 five-letter strings, half of which were generated using letters drawn from the acoustically similar set - CDGTP while the other half were generated using the acoustically dissimilar set - HMJRZ. Items were presented on the screen of a microcomputer, either at a rate of 6 items/s (Fast rate) or at a rate of 2 items/s (Slow rate). Inter-stimulus intervals, during which time the screen remained blank, varied while the display time in both presentation conditions was set at 1/12s per item. For fast presentation conditions an ISI of 1/12s was used while for slow presentation conditions an ISI of 5/12s was used. Following item presentation the screen remained blank for either 1.5s or 8s before recall was required. Subjects were notified that 48 trials would be presented in 4 blocks of 12 trials each. In addition, at the beginning of each block the computer instructed subjects to either 'Articulate' or 'Do not articulate' and told them whether to expect fast or slow presentation. It was explained that 'Articulate' meant that subjects should read all the letters aloud as they appeared on the screen, while 'Do not articulate' meant that they should keep quiet. Headphones were required to be worn throughout the experiment and white noise, produced from a white noise generator, was delivered through them from 2s prior to the onset of the first letter until recall was required. Subjects were expected to remember the order in which the letters were presented and were requested to type the sequence onto the keyboard of the computer.

RESULTS

The results, consisting of the probability of correct response for each of the five serial positions in the 16 conditions (Articulation X Delay X Rate of presentation X Acoustic similarity) were subjected to a split-plot ANOVA with Noise as a between-subjects factor and all other variables as between-subject factors. Mean number of items recalled per list (maximum score = 3.0, there being three repetitions per condition are

shown in the table below.

Noise Level		65 dBC				85 dBC			
Delay prior to recall		SHORT		LONG		SHORT		LONG	
List Type	Rate of presentation	SIM	DIS	SIM	DIS	SIM	DIS	SIM	DIS
No artic.	FAST	1.32	1.84	1.24	1.86	1.52	1.82	1.46	1.90
	SLOW	1.60	2.38	1.56	2.26	1.62	2.74	1.60	2.44
Artic.	FAST	1.46	2.10	1.62	1.74	1.40	1.84	1.80	2.14
	SLOW	1.44	2.64	1.46	2.54	2.00	2.50	2.02	2.86

The following effects reached significance; ($P < 0.05$ or less)

1. ARTICULATION $F(1,18)=7.61$; memory performance was better in articulation than in no-articulation conditions.
2. RATE OF PRESENTATION $F(1,18)=26.86$; memory performance was better under slow than under fast presentation conditions.
3. ACOUSTIC SIMILARITY $F(1,18)=101.6$; acoustically dissimilar letters were recalled better than similar letters.
4. RATE OF PRESENTATION X ACOUSTIC SIMILARITY $F(1,18)=9.33$; the difference in recall between acoustically similar and dissimilar items was greater under slow presentation, confirming that the use of phonemic or articulatory codes was reduced in fast presentation.
5. NOISE X DELAY $F(1,18)=4.61$; loud noise improved recall slightly at short delays but markedly at long delays, implying that the processes of retrieval and rehearsal assumed to be operating during the delay interval are being reinforced by noise.
6. ARTICULATION X RATE OF PRESENTATION X ACOUSTIC SIMILARITY X NOISE $F(1,18)=4.91$; this interaction (see Figure 1) showed that although loud noise generally improved performance, the greatest increment occurred for acoustically similar items presented slowly, in conditions requiring items to be articulated. This suggests that noise reinforces the retrieval of phonological codes and rehearsal, and shows that the effects of noise and articulation are additive here.

CONCLUSIONS

Two main conclusions can be drawn from these results. Firstly we note that the phonemic similarity effect is greatly reduced at the fast rate of presentation, suggesting that its existence relies on the process

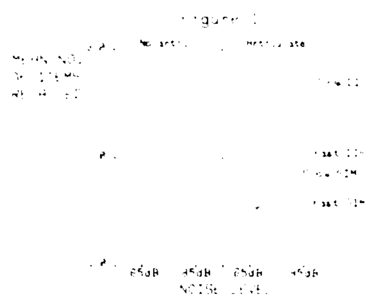

Fig.1 - Mean number of items recalled at different combinations of acoustic confusability, rate of presentation and articulation under each level of white noise.

of rehearsal or some subcomponent of this process such as transfer from a visual to a phonological code.

Secondly we observed that noise improved performance, where either, a long delay existed prior to recall, or where items were presented slowly suggesting that retrieval of phonological codes necessary for rehearsal, is less efficient in noise, and that more time has to be made available for such processes to operate satisfactorily. Further it was observed that noise improved performance of acoustically similar items when subjects articulated them aloud, confirming that articulation affects serial order recall in a similar way to noise, by affecting the phonological stage of processing and rehearsal since presumably both these stages are likely to rely on some type of phonological/articulatory code.

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ANNOYANCE AND PERFORMANCE

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INTRODUCTION

The primary purpose of the investigation reported here is the analysis of the dependence of the annoying nature of a sound on the context in which it is heard. 'Context' is represented here in two ways: in terms of the difficulty of the task (by manipulating signal-to-noise ratio of background noise in relation to events in an auditory vigilance task) and in the individuals' motivation to perform the task (increasing the degree of caution by financial incentives). One intensity level of a sound known to be particularly annoying (Jones, Auburn and Chapman, 1982) was used. The general approach is one of factorial combination of two levels of masking and two levels of incentive. The annoyance associated with each of these manipulations is measured on task performance, and following task performance, on annoyance just experienced during the performance of the task and predictions of annoyance in a setting outside the laboratory. This was designed to examine the extent of generalization of annoyance beyond that of the particular task.

The incentive used in the present study was designed to produce a

cautious response and used a similar pay-off to that employed by Sostek (1979), namely, with the gain for a hit being roughly equivalent to the loss associated with a false alarm.

MATERIALS AND METHODS

The subjects were 80 students drawn from various disciplines. All reported normal hearing. Subjects were randomly assigned to one of four experimental conditions arising from the combination of two levels of incentive and two levels of masking. The task was an auditory version of the Bakan vigilance task based on the form used by Jones, Smith and Broadbent, 1979. The level of noise was set at 85dBC and the level of the auditory digits at either 73dBC (masking condition) or 83dBC (no masking condition). Under conditions of incentive subjects were told that they would, in addition to earning a flat fee of £1, gain 50 pence for each signal they detected correctly and that 50 pence would be taken away for each false alarm reported.

After the subjects had finished the task they were asked to complete a short questionnaire. On analogue scales they were asked to indicate between the poles 'not at all' and 'extremely' their response to the following questions: (i) 'How annoying did you find the noise when you were doing the task?', (ii) 'How annoying would you find the noise if you heard it while sitting quietly and relaxing?'. Between the poles 'much better' and 'much worse' the subjects were asked to rate: 'How much better would you have done without the noise?'. Additionally, subjects were asked to make estimates of the numbers of signals they thought they missed and the number of incorrect reports (false alarms).

RESULTS AND DISCUSSION

The key findings were as follows: (i) masking produced an effect on hits, reducing them markedly; (ii) incentive reduced the number of false alarms, but this effect was not accompanied by an increase in hits; (iii) annoyance during the task was associated with the degree of masking as was the rated loss of efficiency; (iv) predictions about annoyance of the sound in other settings showed an interaction between noise and incentive: annoyance was greater when either noise or incentive (or their combination) was present (see Table1); (v) the association between estimations of false alarms and the number recorded was good when either masking or incentive was present, and (vi) the association between estimated and recorded hits was poor regardless of treatment.

Table 1: Predicted annoyance in quiet as a function of incentive and masking.

MASKING		NO MASKING	
INCENTIVE	NO INCENTIVE	INCENTIVE	NO INCENTIVE
70.0	76.0	74.5	61.5

Annoyance associated with task performance was primarily determined by masking as were estimates of efficiency, based on a prediction of how much better the subject would have done without the noise. However, a quite different picture emerges when subjects are asked for judgements of the likely annoying value of the sound if heard while sitting quietly and relaxing. This judgement depends very much on the conditions under which the task was experienced. If the task was employed with incentive, or with masking, or with incentive and masking, annoyance was much higher than if both masking and incentive were absent. This finding carried with it a number of implications. The first is that annoyance is much higher in those conditions which offer some challenge (either in the form of masking or incentive) to the subject. It may be argued that the subject becomse more 'entrained' to the performance of the task when conditions are challenging (see Jones, 1983, for a general discussion). Support for this proposition comes in the form of the correlation between estimated and recorded false alarms. Here, in all but the case of the no-incentive-no-masking condition, correlations were high. We take this as corroborative evidence that the level of engagement in the task was higher whenever incentive or masking was involved. In general terms it is of note that the annoyance of sounds does seem to depend in large part on the cognitive context in which they were previously encountered, the extent to which the noise in question posed difficulties in perception and the extent to which the noise influenced the

individual's goals and agendas.

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A CROSS-CULTURAL STUDY OF NOISE ANNOYANCE A COMPARISON BETWEEN BRITAIN GERMANY AND JAPAN

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INTRODUCTION

Environmental noise is a world wide problem If we are to discuss these problems on a global basis, it is important that we have data on the cross-cultural perspectives and problems associated with noise. When attempting to study cross-cultural perspectives and attitudes, it is necessary to examine whether the meanings of the terms used and associated with noise, are similarly understood in differing countries. Cross-cultural studies within Europe have previously been conducted, but the scope of the present study encompasses both oriental and occidental countries

MATERIAL AND METHODS

The study was based upon a questionaire survey which was presented to subjects in their native language. Construction of the original questionaire was undertaken in Japanese A German version was constructed via a discussion in English An English version was developed from the German version, and finally both the English and German versions were translated back into Japanese The back-translations were then compared with the Japanese original and where disagreement occurred

items were changed Therefore, the final forms of the questionaire in each language were as similar as possible

The surveys were conducted in Japan, Germany and England during the end of 1980 and beginning of 1981 The subjects were comprised of 110 English, 457 German, and 434 Japanese University students Three different methods were used in the questionaire to illicite information regarding a) attitudes towards noise, b) the acceptability of countermeasures to noise problems; c) to measure the meaning of concepts concerning noise, society and culture, and, d) to obtain basic *demographic* data on the subjects

Attitudes towards noise were obtained by asking subjects to respond using one of three response catogories (aggree, neither agree nor disagree, disagree) to seven statements concerning the subjects attitudes and actions in response to environmental noise (Q1. If my neighbours make noise, I tolerate it because I also make noise myself occasionally, Q2 My neighbour's noise is part of my daily life, therefore I enjoy myself with my neighbour about the noise, Q3 I tolerate, on no account, being annoyed by my neighbour's noise, Q4 My neighbours and I make noise ourselves! Why should we, therefore, make the least possible noise in our daily life?, Q5. I should possibly make no noise, so as not to bother my neighbours; Q6 If my neighbours complain about my noise, then I should immediately stop the noise: Q7. If my neighbours complain *about the noise from* my home, then I say, "we both make noise in our daily life and therefore both of us must also endure it") The acceptability of various noise countermeasures was obtained using a paired comparison technique with five statements concerning noise countermeasures Measurement of the meaning of concepts concerning noise, society and culture were undertaken using a form of Osgood's (1957) semantic differential

RESULTS

The results from the items recording the respondents attitude towards noise is shown in table 1 Thess seem to indicate that the English and German respondents are tolerant of noise eminating from their neighbours as they themselves occasionally make noise In contrast, Japanese respondents appear to be more concerned with making as little noise as possible in order to avoid bothering their neighbours

Analysis of the paired comparison data on the acceptability of countermeasures to noise is presented in table 2

	Q 1 yes	Q 1 no	Q 2 yes	Q 2 no	Q 3 yes	Q 3 no	Q 4 yes	Q 4 no
England	76	9	20	44	20	55	29	28
Japan	18	39	12	60	38	18	5	83
Germany	73	11	4	74	6	68	11	59

	Q 5 yes	Q 5 no	Q 6 yes	Q 6 no	Q 7 yes	Q 7 no
England	44	32	48	18	31	45
Japan	79	4	66	3	6	69
Germany	52	20	44	19	18	52

Table 1. Percentage responses in the 'yes' & 'no' catogories for each of the questions in part A.

The German and Japanese respondents are predominantly concerned with arranging private regulations with their neighbours to avoid noise. Whereas, the English respondents negotiate with their neighbours themselves to see that the noise is stopped.

Paired comparison statements

	(a)	(b)	(c)	(d)	(e)
England	0.93	0.90	-0.47	-0.62	-0.74
Japan	0.43	0.53	-0.06	-0.37	-0.52
Germany	0.83	0.94	-0.52	-0.82	-0.43

Table 2 Weightings of paired comparisons data (statements: (a) I negotiate myself with my neighbours to see that the noise is stoped, (b) I arrange private regulations with my neighbours to avoid noise, (c) I ask some other person to negotiate with my neighbours because of the noise, (d) I hope for severe legal regulations, (e) I don't undertake anything.).

For both the Japanese and English subjects, inaction is the least desirable situation. With the German subjects, the use of legal regulations, as a form of noise control, is seen

as the least desirable form of noise countermeasure

	NOISE			LOUDNESS			ANNOYANCE		
	E	G	J	E	G	J	E	G	J
1	5.3	6.2	5.8	5.8	5.8	4.1	6.1	5.7	5.4
2	4.8	6.0	6.3	5.1	5.5	3.9	6.1	5.9	6.0
3	3.2	2.0	1.8	2.6	2.4	3.9	2.3	2.6	2.2
4	4.3	5.2	6.2	4.4	4.7	3.9	5.0	5.1	5.8
5	3.1	2.5	3.1	2.8	3.0	4.7	2.7	3.5	3.6
6	3.0	2.0	1.7	3.0	2.6	4.2	1.9	2.3	2.0
7	2.8	2.1	1.9	2.2	2.6	3.0	2.5	2.9	2.3
8	4.7	6.0	6.6	4.9	5.3	3.9	6.2	6.0	6.2
9	2.9	2.0	2.4	2.7	2.6	4.7	1.7	2.3	2.7
10	5.1	5.3	5.2	5.6	4.8	5.1	5.2	4.6	4.9
11	3.4	1.9	1.3	3.2	2.4	4.2	1.8	2.0	1.7

Table 3. Semantic differential scores on a 1 to 7 scale for the concepts of "Noise", "Loudness" and "Annoyance" by country of sample (adjective pairs: 1. soft - hard; 2. beautiful - ugly; 3. violent - gentle; 4. clean - dirty; 5. sharp - dull; 6. discordant - harmonic; 7. strong - weak; 8 pleasant - unpleasant; 9. tense - relaxed; 10. powerless - powerful; 11 undesirable - desirable).

Data gathered from the semantic differentials included the concepts of "noise", "loudness" and "annoyance" (Table 3). In the case of "noise", the profiles are similar for all three countries although, the variance in the English sample is less than that for the others. With the concept of "loudness", it is the Japanese profile which differs from the other two profiles. The concept of "annoyance" was similar for all three countries.

CONCLUSIONS

It is apparent that there are a number of important aspects of noise perception and attitudes that differ significantly between England, Germany and Japan. These should be born in mind when comparing results across countries.

THE SUBJECTIVE SYMPTOMS AND NOISE ANNOYANCE OF WORKERS EXPOSED TO IMPULSE NOISE AND CONTINUOUS NOISE

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INTRODUCTION

The aim of this study is to compare the subjective symptoms and noise annoyance among three groups of workers. One group was exposed to impulse noise, the second to continuous, steady-state noise, and the third was a control group with no exposure. The relationships between subjective symptoms and noise annoyance ratings were also surveyed with respect to the mental load factors of work, and individual factors.

MATERIAL AND METHODS

The group exposed to impulse noise comprised 99 men from a shipyard. The group exposed to continuous noise consisted of 43 men from a cab factory. The control group contained 38 men from an open ; an ship drafting office. All the subjects were younger than 46 a old. The average noise levels varied between 86-111 dB(A) at the shipyard, and 82-95 dB(A) at the cable factory. The average noise exposure time in the impulse noise group was 5.7 a, and 8.6 a in the continuous noise group.

The workers completed a two-part questionnaire. The first part included items on subjective symptoms (34 symptoms) and factors of the mental load. The other part was compiled of modified Eysenck Personality Inventory (EPI-C) and Weinstein's noise sensitivity scale.

RESULTS

Subjective symptoms

Compared to the controls, the noise-exposed workers reported significantly more tinnitus, irritability (especially after work), feelings of tired limbs, difficulties in falling asleep, and nervousness. Moreover, the impulse noise group reported significantly more undue fatique (especially after work) and staggering, and the continuous noise group reported significantly more symptoms of diarrhoea. The noise-exposed groups did not differ much from one another in terms of single symptoms.

The symptom data was factor analysed for dimensionality. The purpose was to render it in a few combined symptoms. The five factors arrived at were interpreted in terms of 1) concentration difficulties, 2) hearing symptoms, 3) sleep disturbancies and anxiety, 4) sensomotoric symptoms and 5) fatique. Only those symptoms that carried the highest factor loadings were selected for each combined symptom.

Discriminant analysis was used in order to get the best group differentiation in terms of the combined symptoms. "Hearing symptoms" and "sensomotoric symptoms" were left out of the analysis. The analysis gave two discriminant functions. The first one (I) was strongly related to symptoms of sleep disturbancies, anxiety and fatique. The workers exposed to noise reported this syndrome significantly more than the controls ($P<0.001$). The second function (II) was strongly related to symptoms of concentration difficulties and fatique. The impulse noise group reported this syndrome the most, and the

continuous noise group the least ($p<0.05$) (figure 1).

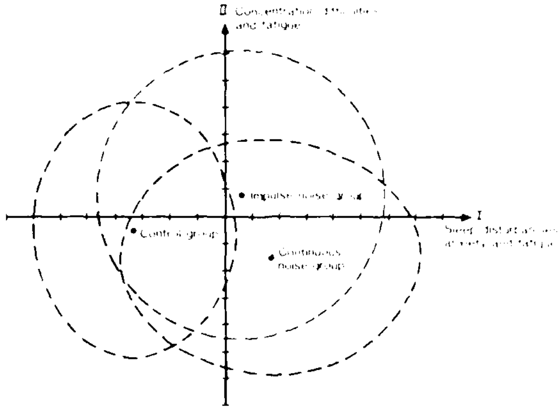

Fig. 1 - The means (dots) and standard deviations (broken line) of the groups on discriminant functions.

Stepwise linear regression analyses pointed out that, in the impulse noise group, 33 % of sleep difficulties and anxiety was explained by social isolation, impulsivity, mental load of environmental factors, hard working tempo, noise sensitivity and overtime work. In the continuous noise group, 38 of sleep difficulties and anxiety was explained by mental load of environmental factors, negligence of ear protectors, and noise exposure time.

In the impulse noise group, fatigue was related to mental load of environmental factors, physical load of work and a fast tempo of work. In the continuous noise group, fatigue was related to noise sensitivity and physical load of work.

The concentration difficulties in impulse noise group were related to social isolation, hard working rate, and also to the mental load of sudden, loud noises.

Noise annoyance

Noise annoyance, and noise level estimates were strongly related, Both groups that were exposed to workplace noise found it socially annoying to an equal extent. In this respect, older workers found it more annoying than younger ones. The impulse noise group rated workplace noise more detrimental to their work than the continuous noise group. In the impulse noise group, these ratings of detrimental effect were, besides related to noise level estimates, also related to noise sensitivity, mental load of sudden, loud noises, and physical load of work.

CONCLUSIONS

The results showed that compared to controls, the groups exposed to noise had significantly more subjective symptoms of neurotic nature. The appearance of symptoms was not uniformly related to the duration of noise exposure. Other environmental and individual factors can modify the effects of noise on the prevalence of symptoms (Tarnopolsky et al. 1980).

Compared with the workers exposed to continuous noise, the workers exposed to impulse noise had more symptoms of concentration difficulties. They also rated the noise in their environment as more detrimental to work. Impulsive noise often has a complex and unpredictable temporal structure, and can have a more distracting influence on performance than noises with a simpler temporal structure.

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Team No. 5

Noise Disturbed Sleep

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Invited Papers on Specific Topics

RESEARCH ON NOISE-DISTURBED SLEEP SINCE 1978.

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In the early 1980's a tendency emerged in the area of research concerning noise disturbance and sleep. This tendency was to considerably increase the number of sleep recordings at home rather than in the laboratory setting.

Research on the direct or indirect effects of noise on sleep has given no definite answers as to what are the major factors of sleep disturbance.

It is still difficult to draw the borderline between what is a physiological and a pathological response to the environment.

Although the results of some studies make no firm conclusions about the effects of noise on health, they have revealed the importance of certain factors, which until now have been underestimated or even ignored.

The need to pursue and to increase certain approaches in this area of research is evident, although the cost of these types of studies is a limitation factor.

LABORATORY VERSUS HOME STUDIES

The two experimental approaches have been quite often opposed and the arguments pertaining to this discussion are numerous.

In 1979, Coates et al. published a study where they compared, in the same group of subjects, laboratory versus home recordings. Variances

of total sleep time and latency to sleep onset were greater in the laboratory than at home. Between and within subject variability was smaller at home in : total sleep time ; latency to sleep onset ; amount of stage 1 and 2 sleep. On the contrary, minutes spent awake after sleep onset, number of arousals and REM sleep quantity were less variable in the laboratory than at home. Coates et al. considered that, taken together, these data do not argue for the superiority of sleep recordings in one location over the other. Rather, they suggest that the relative reliability of the data varies from one location to another.
Therefore, it seems reasonable not to oppose laboratory to home studies. Infact they are complementary and they respond to different purposes.

Studies made in the laboratory often allow exploration of new methodologies and techniques, or stress the importance of a specific factor. This is possible due to the knowledge and the control of ambient factors that may interact with others.
Noises used in the laboratory are played back through a reproduction system and they are generally well calibrated and individualized. They can be produced at a very precise time of the night, within certain stages of sleep and stopped at will. Such an experimental approach is found in studies of auditory arousal thresholds (Bonnet et al., 1979 ; Johnson et al., 1979).

Studies made in the laboratory are limited in duration, however, and it is quite unusual to have an experiment lasting more than a month. Thus, long term habituation to noise cannot be studied in this manner.
Therefore, it is necessary to make studies in the home each time that real ambient conditions will be examined and especially when recordings will be repeated and separated by long intervals.

In most cases the home environmental situation will be constituted by several ambient factors in addition to several, and not one, ambient noise. The knowledge of the noise condition will not be based on the identification of each individual noise but rather on a global evaluation of the noise environment, to which the subject is submitted.

The total suppression of ambient noise will be impossible at home, and thus the only possible way to change the ambient condition will be to modify the noise characteristics by using noise insulation techniques or by opening the windows (Jurriëns et al., 1981).
At home it will be sometimes difficult to control other environmental factors such as ambient temperature and humidity or air confinement.
Since 1978, a large body of studies have been made at home (Eberhardt et al., 1982 ; Hofman et al., 1981 ; Horonjeff et al., 1982 ; Jurriëns, 1981 ; Jurriëns et al., 1981 ; Vallet et al., 1980 ; Vallet et al., 1981 ; Wilkinson, 1981).
These studies have shown the variability of results due to experimental locations, subject population and even techniques used. However, as shown by Jurriëns et al. (this volume), certain studies have demonstrated common findings and thus these findings are gaining a more substancial signification.

In addition, studies made at home are going to give more definite answers to the question of long-term habituation to noise. Vallet et al. (this volume) have shown that it is possible to rerecord the same subjects after several years spent in the same location.

WHAT SHOULD BE MEASURED ?

The effects of noise on sleep are often immediate and of short duration. Therefore, their repercussion on the global structure of sleep is sometimes almost inexistant.
Among these immediate effects, we may quote the electrophysiological and cardiovascular responses to noise. The direct relationship that exists between noise and the modifications it provokes is easier to show in the laboratory due to the fact that stimuli are generally presented individually.

The types of immediate effects depend on the recording techniques used and the variables considered. The electroencephalogram gives an information on sleep stage changes but also on more discrete modifications such as activation phases or phasic EEG events (K complex for example).

The signaled awakening is used in certain studies and it allows a fine location of the disturbing event (Horonjeff et al., [illegible]). Body movements can be considered alone or associated with other electro-physiological measures (Öhrström et al., 1983). Cardiovascular *responses include heart rate and finger pulse amplitude* (Muzet et al., 1980), and they are sometimes associated with respiratory rate changes (Muzet et al., this volume).

These phasic modifications are sometimes moderate and their importance depends mainly on the number and the intensity of the stimuli.

The global evaluation of sleep disturbance may be possible by considering the sleep stage structure (i.e. time to fall asleep, time spent in the different sleep stages, number of sleep stage changes, REM sleep rhythmicity, etc...). This kind of evaluation is used each time that the noise pattern is too complex to examine the effects due to individual noises.

The global evaluation of sleep disturbance can also be made by questionnaires which are associated or not with electrophysiological recordings (Vallet et al., 1982 ; François, 1982). In some studies, mood scales answered during the day (Ehrenstein et al., 1980 ; Öhrström et al., 1982) and/or daytime performances (Jurriëns, 1981 ; Öhrström et al., 1982 ; Wilkinson et al., 1980 ; Wilkinson, 1981) can also be used as very precise indicators of sleep disturbance.

WHAT NOISE EFFECTS SHOULD BE AVOIDED ?

Firstly, it must be pointed out that people's complaints about noise, are sometimes far from researchers preoccupations.

Vallet et al. (1982), however, noted that 60% of the surrounding population of Roissy airport complained about noise in the evening, while 40% complained about noise during the night. This finding stresses the numerical importance of those people annoyed by noise.

This subjective feeling is sometimes amplified in people who estime themselves as being poor sleepers. It has been shown that poor sleepers complain of nocturnal awakenings, and feel that they are easily awakened by noise. In addition, they have trouble returning to sleep after nocturnal arousals. In the morning they usually feel

fatigued and they consider that they have not had enough sleep, having had long sleep latencies and frequent awakenings during the night. However, despite claims of being "light" sleepers, who are easily awakened by noise, poor sleeper's auditory arousal thresholds have been found to be the same as those of good sleepers (Johnson et al., 1979).

In a recent study, Öhrström et al. (1982) noted that the higher the noise level, the poorer the sleep quality. They also mentioned that compared with intermittent noise, continuous noise had a significantly smaller effect on sleep quality. In addition, performance and mood tended to be worse after intermittent noise exposure.

A poor sleep quality associated with a feeling of fatigue may lead to a deterioration of daytime performances. Wilkinson (1964, 1969) suggested that a good performance test in connection with sleep deprivation experiments should be monotonous, relatively complicated and fairly long. In a later study (1981) he found, however, a significant increase in simple reaction time with a test lasting 10 minutes. This result was also found by other teams (Jurriëns et al., this volume).

Annoyance due to ambient noise may lead to different behaviors that are difficult to measure. Noise-exposed people may organize protests, legal actions, or move to a quieter area. We now believe that noisy environments might explain the increase of medical complaints and drug consumption. Therefore, the economical repercussions of noise might be considerably greater than what has been expected until now.

Researchers mainly consider the noise effects that are measurable, although their importance is not always proven. This is due to the fact that the long-term biological consequences of moderate and repeated sleep modifications provoked by noise, are almost unknown.

Nocturnal awakenings can be noticed either by the experimentator or the noise-exposed subject. The importance of this factor is not questionable and it is commonly used (Ehrenstein et al., 1980 ; Griefahn et al., 1978 ; Griefahn, 1980 ; Horonjeff et al., 1982 ; Thiessen, 1978 ; Vallet et al., 1980 ; Vernet, 1979 ; Wilkinson, 1981). The different techniques used (awakening signaled by pushing a button, or confirmed EEG awakening) show that the perception of awakening is sometimes very different for the experimentator and for the sleeper.

In the morning the number of nocturnal awakenings is generally not remembered and is often underestimated by the subject.
Concerning the number and the duration of sleep stages, although they can be easily quantified, their biological signification is still imperfectly known. Ehrenstein and Weber (1980) expressed some doubt on the importance of sleep stage patterns as suitable indicators for the determination of noise effects upon sleep.

These authors observed an important reduction of slow wave sleep and a moderate decrease of REM sleep during the first night of noise exposure, but only the latter reduction was maintained for several nights.

Are the cardiovascular responses to noise important from a health point of view ? Muzet et al. (1978) demonstrated a clear relationship between the noise peak intensity and the amplitude of heart rate and finger pulse responses. These cardiovascular responses to noise do not habituate during the night and their importance depends on the age of the subjects (Muzet et al., 1981).
The importance of these cardiovascular modifications is suggested by the nature of these responses. They are purely reflexes and they do not correspond to any energetic need of the sleeping body. The harmlessness of these repeated modifications remains to be demonstrated. If long-term exposure to noise can be harmful it should be because these cardiovascular modifications seem not to habituate (Ehrenstein and Weber, 1980 ; Muzet et al., 1980).
Long-term habituation of noise effects is certainly a major problem and it will have to be more deeply studied in the future. Several authors noted a possible habituation for sleep modifications such as nocturnal awakenings or reduction of amounts of slow wave sleep (Ehrenstein and Weber, 1980 ; Thiessen et al., 1978 ; Muzet et al., 1981), while REM sleep reduction can be maintained over several nights of noise exposure (Ehrenstein and Weber, 1980). Results concerning mood and sleep quality sometimes differ. Ehrenstein and Weber (1980) found no adaptation for subjective mood over several nights while Muzet et al. (1980) noted a rapid subjective adaptation to the noisy environment after 2 to 3 consecutive nights. Such a difference could

be explain by the fact that the noise intensity and the nature of the noise were not the same in the two studies. It seems reasonable to think that whether or not adaptation occurs depends on certain characteristics of noises.

HOW AND WHOM TO PROTECT ?

The means used to protect people against noisy environments are frequently difficult to apply, costly and sometimes they create new constraints. Double glazing is efficient only if windows are maintained closed, and ear plugs are not tolerated by certain persons. Sometimes the remedy can be worse than the situation itself. It appears from recent studies that daytime and nighttime exposure to noise could partly explain the observed increase of tranquillizer and hypnotic consumption. Such a tendency has been suggested by Knipschild (1977) and by Lambert et al. (1980) around international airports. In a recent report, François (1982) noted an increase in the anxiety rating of the surrounding population of Roissy airport from 1[illegible] to 1981.

The efficacity of hypnotics in the protection of sleeping subjects against noise is hypothetical. Hypnotics seem to increase arousal thresholds (Bonnet et al., 1979 ; Johnson et al., 1979) and to reduce the number of some electrophysiological responses to noise (Ehrenstein et al., 1980 ; Muzet et al., this volume, Saletu et al., 1980). However the reduction of the amplitude of cardiovascular responses to noise is only moderate and seems to be limited to the first night under the influence of the hypnotic (Muzet et al., this volume).

Most of the studies that have been done up until now, have been done on young subjects in good health. It seems reasonable to hypothetize that certain groups of subjects could be more sensitive to noise. There is a lack of studies which take into account the difference in the vulnerability of certain populations to noise-exposure. Havranek et al. (1979) found that children sleeping at school in a noisy area had four times as many body movements during their afternoon nap as kindergarten children sleeping in a relatively quiet area. In addition, these noise-exposed children took a longer time to fall

asleep, and had smaller total sleep times than children sleeping in quiet areas.

Such results show the importance that should be given to the exploration of groups of subjects who are believed to be more annoyed by noise than other groups. It is also necessary to sight the results obtained by Blois et al. (1980), who showed that noise during the daytime can have an effect on subsequent night sleep.

The results mentioned in this report demonstrate that studies concerning the effects of noise on sleep must be pursued despite their complexity, and they should be extended to groups or situations that have until now, been insufficiently considered.

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DISTURBANCES OF SLEEP - INTERACTION BETWEEN NOISE, PERSONAL, AND PSYCHOLOGICAL VARIABLES.

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INTRODUCTION

This study is part of a joint European project designed to demonstrate the dependency between: Noise - Sleep disturbances - Subjective assessment - Performance.

METHOD

The sleep of 10 couples, 25-63 years old, living in streets with high traffic load for at least 14 months was recorded during 12 consecutive nights each. The subjects were healthy, had normal hearing, did not take drugs, and were asked not to drink alcohol during test series. They were selected from 24 subjects who completed an extensive questionnaire sent out by mail.

All subjects slept under both noisy and quiet conditions. The experimental condition was executed during the 6th to 10th night. For 5 couples normally sleeping with closed windows noise level was raised by opening the windows. For the other 5 couples noise level was reduced by using earplugs. The average difference between both conditions was about 9 dB(A) for L01 and about 7 dB(A) for the equivalent noise level.

During test series EEG, EOG, and noise level were recorded

continuously throughout the night. [illegible]
the subjects had to answer [illegible] questionnaire [illegible]
plete a four-choice-reaction-time [illegible].

Personality factors were examined prior to [illegible] recording.

The [illegible] were divided into 8 subgroups by

- experimental condition ('earplugs' and 'without')
- sex
- age (up to 40 years and more than 40 years)
- [illegible] living in the same dwelling (up to 4 years [illegible] than 4 years).

[illegible] procedures the first two nights were excluded. [illegible] are significant on the 1 -level.

RESULTS AND DISCUSSION

For all subjects combined stage-4-latency was prolonged during noise, the number of sleep cycles was reduced, and sleep latency was estimated to be longer.

Experimental subgroups

The 2 experimental subgroups reacted differently. For the earplugs-group it was found that sleep latency as indicated by the EEG decreased during quiet, the number of complete sleep cycles increased as well as the number of sleep-stage-changes.

The effect of earplugs is far less than recorded by Strale (1974, 1975) and Otto (1970). But those studies were executed in the laboratory and it is often reported that reactions are bigger in the lab (Ehrenstein et al., 1982; Goldstein & Lukas, 1980; Vallet et al., 1980). The small difference is probably related to the content of information. Attenuation by earplugs is only temporary and noise is still audible. The situation per se is as annoying as before, especially due to the fact

Table 1: Reactions due to noise in different corresponding subgroups. N = noise, Q = quiet
Global reaction based on nights 3-12, Average reaction: nights 3-7&10, Spontaneous reaction: nights 5,6,10&12
Wilcoxon-test (noise vs quiet), U-test (group 1 vs group 2), '*' = probability of error p < 1%

	Global reaction			Average reaction			Spontaneous reaction		
	N - Q p	N - Q p	p	N - Q p	N - Q p	p	N - Q p	N - Q p	p
1. E X P E R I M E N T A L G R O U P	earplugs	windows	e/w	earplugs	windows	e/w	earplugs	windows	e/w
Sleep latency (minutes)				6.6*	.6	*		-	
Number of complete sleep cycles	-.6*	.2	*	-.4*	.5			-	
Number of sleep stage changes	12.1*	6.3	*	-9.7*	5.7	*	-	-	
Estimated sleep quality				-1.4	9.0*		-1.3	16.8*	
Estimated fatigue				3.8	-6.9	*	-	-	
Estimated sleep latency (minutes)							8.6	9.1*	
2. S E X	female	male	f/m	female	male	f/m	female	male	f/m
Stage 4 latency (minutes)		-		5.3*	12.3			-	
Intermittent wakefulness (minutes)		-		3.6	-7.1*	*			
Number of complete sleep cycles	-	-		-.5*	-.3		-	-	
Number of awakenings				.9	2.8*	*	-	-	
Estimated sleep quality		-		11.9*	4.4		16.9*	1.4	
Estimated sleep latency (minutes)	11.8*	1.5		16.4*	-1.5		20.1*	2.4	
Estimated time awake (minutes)	-	-		19.3*	-4.2	*	-	-	
Errors (evening-morning), 2nd half	.9	2.9*		.4	3.3*				
3. A G E	<=40yrs	>40 yrs	(/)	<=40yrs	>40 yrs	(/)	<=40yrs	>40 yrs	(/)
Stage-4-latency (%)	8.3*	.7		-			25.1*	15.9	
1st sleep-cycle, stage 1 REM (minutes)	3.4	6.9	*	3.3	9.3*	*	-	-	
1st sleep-cycle, SWS (minutes)	-	-		-8.4*	-.4		-	-	
Stage 1-REM (minutes)				-			13.7*	-5.2	
Number of complete sleep cycles	-	-		.5	-.6	*	.9	-.5	*
Average cycle-length (minutes)				-4.6	8.6	*	-	-	
Number of errors (evening-morning)	-	-		-1.0	-8.9*		-	-	
4. R E S I D E N C E - T I M E (years)	< 4 yrs	> 4 yrs	(/)	< 4 yrs	> 4 yrs	(/)	< 4 yrs	> 4 yrs	(/)
Sleep latency (minutes)	3.4	2.7*			-		-	-	
Stage 4 latency (minutes)	-9.7	11.9	*	-	-		-	-	
1st sleep cycle, stage 1-REM (minutes)		-		-	-		-7.5	8.5	*
1st sleep cycle, SWS (minutes)		-		-	-		-21.7*	-4.2	
Stage 1 REM (%)	.5	3.9*		1.5	4.7*		-	-	
Number of errors in the morning		-		-	-		.0	.4*	

that noise persists unattenuated during the day. Moreover, the earplugs themselves may be a disturbing factor. Thus the beneficial effect of sound attenuation may be vastly neutralized.

On the contrary no objective alterations were recorded for the windows-group. But after nights with open windows the subjects felt that they had needed more time for falling asleep, they were more tired in the morning and assessed to have had a worse sleep quality.

The subjects of the windows-group usually shut the windows because of the traffic noise. Therefore they are convinced to sleep worse during the experimental nights. While awake prior sleep onset they receive the noise objectively louder and they are probably afraid not to get enough sleep. The difficulty in getting asleep is then interpreted as prolonged sleep latency.

Sex

During nights with higher sound levels female subjects revealed an increase of stage-4-latency whereas the number of complete sleep cycles decreased. Performance was not impaired, but the next morning the women assessed that they had spent more time for falling asleep and for intermittent wakefulness and that they had slept worse.

The discrepancy between physiological and subjective results is in accordance with the literature. From social surveys it is well known that women feel to sleep worse than men. Sleep recordings in the lab and in the field, however, do not support these findings. The conclusion then is that women are especially sensitive to exogenic stimuli. When awake they are anxious not to get asleep soon and this is probably misinterpreted as a lengthening of the awake-periods (Hartmann, 1970; Jurriens et al., 1981; Kahn & Fisher, 1969; Langdon & Buller, 1977; Lukas & Dobbs, 1972; McGhie & Russell, 1962; Meier & Müller, 1975; Monroe, 1969; Muzet et al., 1973; Tune 1968,

1969; Vallet et al., 1983; Wilkinson & Campbell, 1980).

The lack of a concomitant impairment of performance results perhaps from a general need of ambition to execute the tests as quick and as good as possible.

The reactions of male subjects are partly in the opposite direction. The number and duration of intermittent wakefulness is reduced in noisy nights, suggesting even a better sleep. Subjective assessment is not related to the different conditions but performance was qualitatively impaired.

No other subgroup demonstrates better the discrepancy between EEG, subjective assessment, and performance. Similar results are reported in several publications and most of the authors feel that the significance of the EEG is highly questionable (Muzet, 1980; Ehrenstein & Müller-Limmroth, 1980).

Age

Subjective assessment was altered neither for the younger nor for the older subjects. Regarding the physiological data the younger group seems to be somewhat more disturbed. For the latter group latency to slow-wave-sleep increased in noisier nights and this stage then was reduced within the first sleep cycle. This result harmonizes well with other publications (Eberhardt & Akselsson, 1980; Vallet et al., 1983). The structure of sleep was altered by lengthening of REM-sleep and a shortening of the average cycle length, combined with an increase of the number of sleep cycles. This number became less in older subjects. For them REM-time was longer in the first sleep cycle. However, psychomotor performance which is not affected in younger subjects is qualitatively impaired in the older group. The frequency of errors is greater in the morning compared to the previous evening. This difference becomes more important during noisy conditions.

Though the physiological reactions are contradictory to the hypothesis that older people become more sensitive to noise

the performance data are well in accordance with social surveys and experimental results (Kramer et al., 1971; Langdon & Buller, 1977; Lukas et al., 1969, 1971; McGhie & Russell, 1962; Meier & Müller, 1975; Steinicke, 1957).

REM-sleep reduction is often reported to be the most consistent noise effect. The contrary was found in subjects more than 40 years of age. But, after having summarized the data of 13 publications comparable in method and evaluation, no difference was found for REM-sleep between noisy and quiet conditions (Griefahn, 1980; Collins & Iampietro, 1972; Globus et al., 1973; Griefahn & Jansen, 1978; Griefahn et al., 1976; Knauth & Rutenfranz, 1975; Kramer et al., 1971; Lukas & Dobbs, 1972; Müller-Limmroth & Ehrenstein, 1974, 1976; Muzet et al., 1973; Pearsons et al., 1974; Scott, 1972; Townsend et al., 1973; Vallet et al., 1975).

Years living in noisy streets

The sleep of those who lived up to 4 years in the dwelling where the recordings took place was altered only during the first sleep cycle. Latency to stage 4 was shortened, the minutes spent in REM and Delta-sleep were reduced. For those living longer than 4 years at the same location stage-4-latency became longer and REM-time increased within the first sleep cycle as well as its amount during the whole night. Whereas no effect on performance was calculated for the first group the frequency of errors in the morning compared to the previous evening became more important in the latter group demonstrating an impairment of test quality.

The results suggest that people who live in noisy locations are more sensitive to acoustical stimulation. This is already proven in social surveys. Because the human brain is able to distinguish between different stimuli even while asleep it is possible that the psychosocial reactions continue during the night (Rohrmann et al., 1978).

The results of multivariate analysis demonstrate the significance of usual sleep behavior, the preceding day's stress and personality (FPI 8 = 'Gehemmtheit') for falling asleep. Sleep structure then is determined by sex, age, by aggression and extraversion, by subjective health state and usual sleep quality as well. Subjective assessment in the morning is influenced mainly by the time of falling asleep, the usual number of awakenings and by personality (FPI 8) whereas age, test frequency, and nervousness influences performance.

People living more than 4 years in streets with high traffic load tend to have less Delta sleep which may be interpreted as an increased sensitivity to noise.

Overall, if EEG, subjective assessment, and performance are real indicators of sleep quality the influence of noise during the night tends to have a slight negative effect and thus has to be regarded as a stressor which may be detrimental with respect to wellbeing and health. The 3 indicators recorded and reported here are, however, not related to each other. The postulated chain:

noise - sleep disturbances - subjective estimation - impaired performance

is not obligatory but only one possible pathway in the development of detrimental effects caused by noise exposure during the night.

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SLEEP DISTURBANCES CAUSED BY NOISE: ANALYSIS OF A CROSS-SECTIONAL INQUIRY

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INTRODUCTION

Sleep disturbances show the most negative effects of environmental noise (GLOAG 1980). In a study of LANGDON & BULLER (1977) 30% of the residents complained about difficulties to get asleep; 50% of them attributed these difficulties to the noise. 50% reported awakenings during the night whereof 30% were related to environmental noise stimuli. It is not surprising that in sleep studies regarding various environmental stress factors, noise is the most commonly studied stimulus (WEBB & CARTWRIGHT 1978). The important effects of noise related sleep disturbances were also confirmed in experimental studies (EHRENSTEIN et al. 1977; JURRIENS 1981; Vallet et al. 1981). An extensive literature review was given by GRIEFAHN et al. (1976). Based on the literature studied, GRIEFAHN (1980) comes to the conclusion that studies about sleep disturbances caused by noise should not only be performed in the laboratory. The problems have to be solved mainly with epidemiological methods.

THE SUBJECTIVE ASSESSMENT OF SLEEP

The subjective assessment of sleep with interview or questionnaires means that subjects have to judge a situation, which is very different from the waking state. Nevertheless, most of asked people have a good idea of being a "good" or a "poor" sleeper (MONROE 1967). HAURI (1970) or HARTMANN (19[illegible]) believe that the subjective assessment of sleep quality is dependent mostly on number and duration of remembered wakefulness. Besides this, good or poor sleep seems to be related to personality variables, mood changes and slow wave sleep.

Concerning the subjective sleep quality, one has to differ between the assessment of actual (f.e. last night) or habitual (usual sleep behaviour) sleep quality. For instance, WEBB et al. (1976) or DOMINO & FOGL (1980) developed sleep inventories which include items to indicate the more actual sleep quality. The predominant sleepiness was studied by HODDES et al. (1973) with the Stanford Sleepiness Scale. The questions concerning the prevailing habitual sleep quality (f.e. FRANKEL et al.197[illegible]; WEITZMANN 1981) include more global items like:

- usually difficulties to get asleep,
- nightly occurrenced awakenings,
- awakenings too early in the morning,
- enough time to sleep or more sleep time wanted,
- sleep drugs consumption,
- general daily fatigue.

All together the significance of particular sleep parameters whether actual or habitual, whether objective or subjective, is not yet clear. Objective measurements on sleep disturbances can only be validated by the subjective estimation of the people affected. By reviewing sleep deprivation studies, WEBB & CARTWRIGHT (1978) came to the general conclusion, that the main effect of sleep deprivation is the sleepiness which could only be determined by the subjects themselves but which was seldom reflected by objective measuring.

THE SUBJECTIVE ASSESSMENT OF SLEEP UNDER NOISY CONDITIONS IN EPIDEMIOLOGICAL STUDIES

After GRIEFAHN & MUZET (1978) the subjective sleep quality assessment of nights with acoustical stimulation has close connections to the stimuli and moderator variables, as there are: Acoustical and level parameters, age, sex, state of health. In the study of LANGDON & BULLER (1977) the main influencing variables on sleep disturbances were: Noise susceptibility, socio-economic status, age, sex, and sleeping drugs consumption. [illegible] & DAVIS (1977) found no significant correlations between noise level and subjective sleep quality; even after noise reduction of 17 dB(A) there was no close relationship to an improvement of sleep quality. After WEHRLI et al. (1978) preventive measures are good indicators of annoyance reactions, f.e. taking earplugs or closing windows.

Summarizing, it can be stated that in epidemiological studies concerning noise effects on sleep, a variety of moderator variables (besides the noise level) have to be taken into account.

MATERIAL AND METHODS

The study presented here contains the evaluation of questionnaire data, collected on a rather homogeneous population group, highly exposed to road traffic noise coming up from a city highway in Essen, West-Germany. The main interest was the exploration of the sleeping behaviour and its relation to the noise annoyance. About 300 questionnaires were sent by mail to a randomly selected population group living along the city highway. Half of the questionnaires were returned completely filled out. The questionnaire contained items concerning the following topics:

- demographic variables,
- noise annoyance, dust annoyance, smell annoyance,

- sleep habits and attitudes,
- contentment of housing environment,
- job satisfaction and work efficiency,
- health.

The questions were based on similar inquiries in German language (PLEIMES 1972; STRAUCH et al. 1974; BRANDLEN 1970). The predominant noise level was calculated by automatic counting of the number of cars. The average rating levels were L_r = 79 dB(A) between 06:00 a.m. and 10:00 p.m.; L_r = 71 dB(A) between 22:00 and 06:00 (Fig. 1).

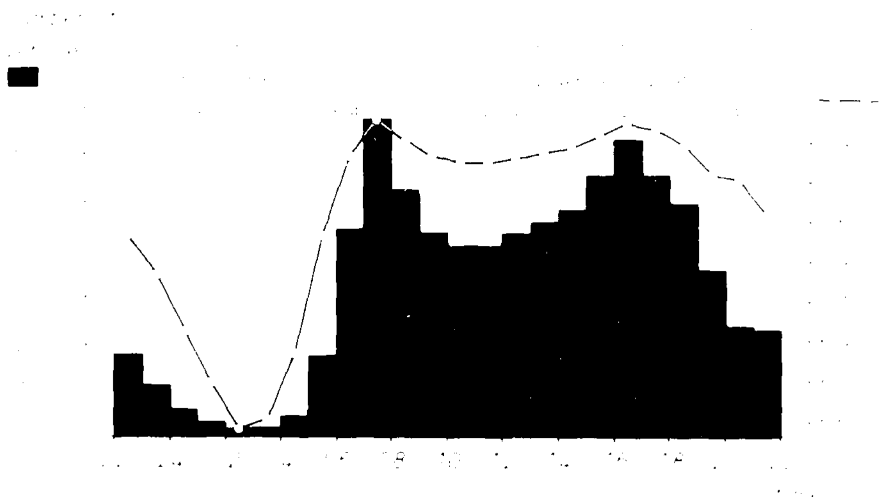

Fig. 1 - Road traffic noise (vehicles/h; 20% trucks); average week-day; city highway A 430, Essen (FRG)

RESULTS

The most often perceived kind of noise was road traffic noise (95,4%). Cars and trucks (87,8% and 80,4%) dominated buses and motorcycles (24,6% and 28,8%). Other kinds of noise sources were not important (railway noise 27,1%; neighbourhood noise 21,7%; industrial and aircraft noise not existent).

The time period with the most noise annoying effect was "the whole day long" (69,2%), followed by "at night" (29,2%). The amount of disturbances caused by noise resulted also from the following statements:

- 55,0% too noisy within the home,
- 70,4% housing environment too noisy,
- 54,6% intention to remove because of noise annoyance,
- 54,6% bedroom in front of the highway,
- 48,3% sleeping with closed windows in the summer,
- 70,4% sleeping with closed windows in the winter,
- 58,8% of those with closed windows because of noise annoyance.

The subjective estimation of the state of health demonstrated that more than 38% felt "good" or "excellent". The results of the various environmental stress factors are shown in Fig. 2.

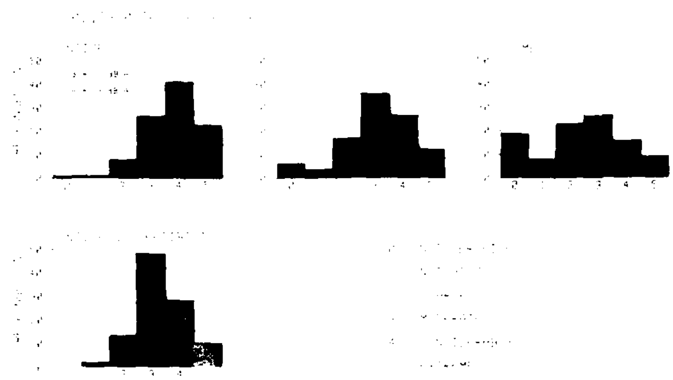

Fig. 2 - Noise susceptibility and annoyance
(questionnaire data, road traffic noise, N 240)

Factor analysis was calculated with those items, which had close relationships to sleep behaviour and sleep attitudes. The extraction of factors was carried out with principal component analysis and varimax-rotation. For the presentation of [illegible] tive estimated sleep disturbances, 2 well-explainable [illegible]

AD-A142 413 NOISE AS A PUBLIC HEALTH PROBLEM: PROCEEDINGS OF THE INTERNATIONAL CONGRE..(U) TURIN UNIV (ITALY) DEPT OF AUDIOLOGY G ROSSI NOV 83 EOARD-TR-84-08-VOL-2 3/6

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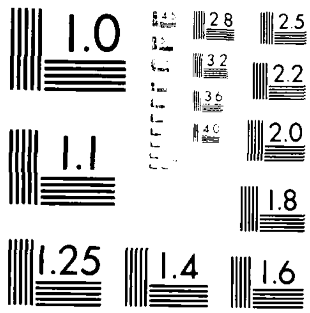

MICROCOPY RESOLUTION TEST CHART

F1 and F3 were used in the following text:

- F1 contained the global self-assessment as a good or poor sleeper with a certain amount of perceived sleep disturbances; F1 was called "sleep quality".
- F3 described the quantitative aspects of sleep, based on items, concerning the assessments about normal or wanted sleep length; F3 was called "sleep need".

It has to be pointed out that the variance explained by these two factors is only 31%. Table 1 gives the correlation coefficients between the most important sleep items and the estimated sleep factor scores F1 and F3 for all subjects. In accor-

Table 1: Correlations between sleep variables and sleep factor scores

	F 1 Sleep quality	F 3 Sleep need
good vs. poor sleeper	.85 ***	.28 ***
difficulties to get asleep	-.83 ***	-.12
awakenings	-.72 ***	-.11
normal sleep length	.42 ***	.68 ***
wanted sleep length	.11	.74 ***
minimum sleep length	-.09	.69 ***
sleep length is sufficient	.31 ***	-.02
worried about poor sleep	-.23 ***	.07
dream quantity	-.16 *	.15
dream estimation	-.27 ***	-.01
bad-tempered in the morning	.05	.24 ***
good getting up	-.04	-.26 ***
plenty of time in the morning	-.12	.05
in a hurry in the morning	.04	.05
time between going to bed and turning off the light	-.20 **	-.05
day time naps	-.07	-.02
taking sleep drugs regularly	-.17 **	.00

dance with our expectations high correlations were found between the variables, which had high loadings on one factor and

the factor scores of this factor. This supports the usefulness of the "estimation procedure with so-called marker variables" for factor scores (PAWLIK 1976). In Table 2 the correlations between noise variables and sleep factor scores are shown.

Table 2: Correlations between noise variables and sleep factor scores

	F 1 Sleep quality	F 3 Sleep need
subjective noise annoyance	-.25 ***	-.02
noise not perceived	.14	-.03
neighbourhood noise	-.10	-.07
industrial noise	-.01	-.01
aircraft noise	.03	.05
construction noise	---	---
railway noise	-.12	-.06
road traffic noise	-.15 *	.03
- cars	-.09	-.03
- trucks	-.20 **	-.04
- buses	-.12	-.10
- motor-cycles	-.12	-.01
noise in the morning	-.09	-.05
- noon	-.14 *	-.11
- afternoon	-.07	.01
- evening	.02	.07
- whole day	-.11	-.08
- night	-.18 **	-.08
dwelling too noisy	-.18 **	.08
noise annoyance in residential district	-.25 ***	.00
change of residence considered because of noise annoyance	-.10	-.12
subjective noise susceptibility	-.34 ***	-.12

Table 3 gives the relations between demographic variables and the sleep factor scores.

Table 3: Correlations between demographic variables and sleep factor scores

	F 1 Sleep quality	F 3 Sleep need
sex	.15 *	-.03
age	-.31 ***	-.15 *
subjective health assessment	.40 ***	.05
unmarried	.19 **	.10
married	-.10	-.03
divorced	.10	.07
widowed	-.16 *	-.14 *
primary school	-.15 *	.01
secondary school	.12	-.01
high school	.07	.00
manager	.05	-.08
official, employee	.29 ***	.03
independent businessman	-.01	.01
skilled worker	.01	-.06
worker	-.02	.01
housewife	-.25 ***	.04
in education	-.03	.06
retired	-.13 *	-.11
unemployed	.09	.14 *

As demonstrated in Tables 1-3, some other variables than those connected with noise annoyance show significant correlations to subjective sleep assessment. This is the case especially for the variables age and health, which can be consi-

dered as possible moderator variables. Furthermore, it is demonstrated that the 3 environmental stress factors (noise, smell, dust) show nearly the same significant correlations to the sleep quality (see Table 4). The connections between the annoyance variables and the sleep quality was analyzed by computation of partial correlations. The subjective noise susceptibility was only regarded as moderating variable between noise annoyance and sleep quality. Table 4 shows that age, health and total number of complaints (that means a general tendency of complaining) are important moderator variables between environmental stress factors and sleep quality. But even under simultaneous control of all moderator variables, the influence of the noise annoyance on sleep quality is still remaining.

Table 4: Simple and partial correlations between moderator variables, annoyance variables and sleep quality (for space reasons not all possible combinations are presented)

Simple and partial correlation with	age	health	number of complaints	sleep quality	sleep quality					
control variables					age	health	number of complaints	age, health	age, health number of complaints	noise susceptibility
age		-.35***	-.22***	-.31***						
health	-.35***		-.16	.40***	.33***		.38***			
number of complaints	-.22***	-.16		-.17**	-.26***	-.12		-.19**		
noise annoyance	.18**	-.20**	.10	-.25***	-.21***	-.19**	-.24***	-.17**	-.16*	-.16*
dust annoyance	.08	-.15*	.17**	-.22***	-.20**	-.17**	-.19**	-.17**	-.14*	
smell annoyance	.11	-.22***	.13	-.21***	-.19**	-.13	-.19**	-.13*	-.11	

CONCLUSIONS

Our data suggest, that in conformity with our expectations annoyance is closely related to subjective sleep quality, i.e. self-estimation as a poor sleeper, difficulties to get asleep, often nightly occurring awakenings, sleep length, worries about poor sleep and unpleasant dreamings. Age, health and noise susceptibility are the most important moderator variables between noise annoyance and sleep: With increasing age,

bad health and noise *susceptibility, the perceived annoyance* is growing, while sleep quality will be assessed worse. Smell and dust annoyance are also correlated with sleep quality; compared with noise annoyance they are of lower importance.

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SLEEP DISTURBANCES - AFTER EFFECTS OF DIFFERENT TRAFFIC NOISES

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INTRODUCTION

In most previous studies, the effect of noise on sleep has been evaluated using EEG measured changes of sleep patterns. Although abundant information exists on the influence of noise on sleep patterns, the medical consequences of these alterations are not well understood. From a medical point of view, studies of subjective sleep quality and other after effects of noise-disturbed nights may yield important information for an evaluation of long term consequences of disturbed sleep. It is reasonable to assume that disrupted sleep over longer time periods could result in physiological and medical effects such as an increased tiredness, decreased capacity to perform and decreased social orientation. Such effects usually disappear after recovery in undisturbed sleep, but there is a risk, if the resting period is chronically disturbed, that these changes will increase in severity over a longer time period.

The aim of the present studies was to develop methods to study after effects of noise-disturbed sleep and to evaluate the importance of

continuous versus peak noise. Effects on sleep quality and mood were evaluated with different questionnaires. The effect of performance was evaluated from a reaction time test, earlier used in sleep studies.

For the purpose of the present experiments it was considered satisfactory to monitor sleep patterns with body movements which largely parallel EEG changes. This registration does not interfere with sleep quality and there is no need for habituation to the measuring equipment.

Experiments were performed in a sleep laboratory and under field conditions. In a first laboratory experiment the effect of intermittent and continuous, even traffic noise was evaluated and in a second experiment effects of intermittent noise with different peak noise levels was used to elucidate the importance of peak levels.

In order to further assess the suitability of the bed movement indicator and the sleep questionnaire, a field study was undertaken in an apartment building before and after noise insulating windows had been installed.

1. LABORATORY EXPERIMENTS

MATERIAL AND METHODS

Subjects. In the laboratory experiments, the subjects were medical students 18-35 years old. Six persons participated in the first experiment and 12 persons in the second experiment.

Locations and experimental routines. The subjects slept in a laboratory furnished as a bedroom with an ordinary bed, comfortable chairs, radio and TV. An area adjacent to the sleeping room was available for preparing food and eating. The temperature in the sleeping room was 18-19°C. During the

week of one experiment, subjects carried out a performance test at 22.00 h. filled in a questionnaire and went to bed at 23.00 h. They were awakened at 07.00, whereafter they filled in another questionnaire and again carried out the performance test.

The subjects slept five or six nights in the laboratory during the second week. The first 1 or 2 days were quiet for habituation and the last 3 or 4 nights the subjects were exposed to different noise climates in a randomized way.

Noise exposure. The noise was taped traffic noise. In experiment I, continuous noise with an even character, Leq 51.4 dB(A) and intermittent noise from 37 single passages of cars with a peak level of 80 dB(A) and an Leq level of 51.4 dB(A) was used. In experiment II, intermittent noise with a peak level of 60 and 70 dB(A) respectively and a Leq level of 34.5 and 42.5 dB(A) was used.

Evaluation of effects

Body movement indicator. Body movements were registered with an indicator fastened under the bed. Movements were calculated as average number of movements per hour or per eight hours of the sleeping period. The movements were registered simultaneously with noise exposure recordings, which made it possible to determine whether a certain noise event had caused a body movement. A positive relation was considered to be present if the movement appeared within 20 s after the noise event.

Sleep quality and mood. An evening questionnaire contained questions about the situation during the day with reference to stress and tiredness. A morning questionnaire contained questions on time required to fall asleep, sleep quality, the number of awakenings and the reason for them, tiredness and irritability. The subjective responses were graded by using a 100 mm line with the endpoint markings poor-good, tired-alert and irritated-friendly.

The mood questionnaire (Sjöberg et al., 1977), contained a total of 71 different adjectives with reference to feeling and mood. These words are grouped to form six different variables; pleasantness, activation, calmness, social orientation, control and extroversion. The scale runs from 1 to 4, allowing the test person a choice as to whether he agrees definitely, slightly, not or definitely not to the mood adjective in question.

Performance test. An apparatus based on the principle described by Le Vere 1975, was developed to test performance. The apparatus is shown in Figure 1.

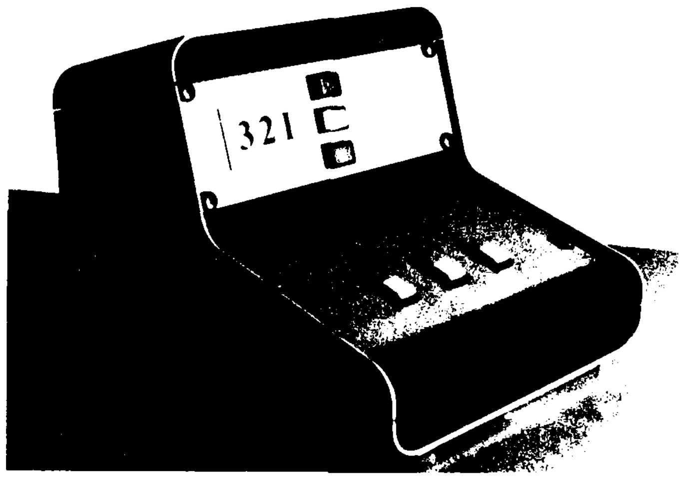

Figure 1. Performance test apparatus

The test is a three choice reaction speed test with a built in memory function. The test results were calculated as the number of correct answers, the number of false answers and the average time in ms between correct answers. The test was administered for 20 minutes and the results were evaluated for each 10 min period. As the test required learning and practice the subjects trained 40 min/day for five days before experiment. The results were calculated as the difference between the evening and morning results after the night spent in the laboratory.

RESULTS

Body movements. During experiment 1, where subjects were exposed to continuous and intermittent noise, five of six persons showed an increased number of movements during a night with intermittent noise. The average number of movements increased from 145 to 169 (16%) during a night with continuous noise and to 177 (22%) during a night with intermittent noise.

An average of 63% of the passages of vehicles caused a movement by the test persons.

During experiment 2 with intermittent noise at different peak levels, the number of movements during nights increased with 11%. The difference was significant (Students' t-test one- tailed) between the reference night and the night with 60 dB(A) intermittent noise. During nights with 70 dB(A), the subjects had significantly more awake time (70 min (mean value)) according to the questionnaire compared with 26-30 min during reference nights and nights with 60 dB(A). Body movements were caused by 40% of tł passages at 60 dB(A) and 54% of the passages at 70 dB(A). The number of movements increased during the time periods 2400–0200 and 0500–0700 when the number of noisy events was highest. The correlation between the proportion of movements and the hourly Leq was 0.83–0.86 for the noisy nights. During quiet nights the movements were distributed in a different way. This is illustrated in figure 2.

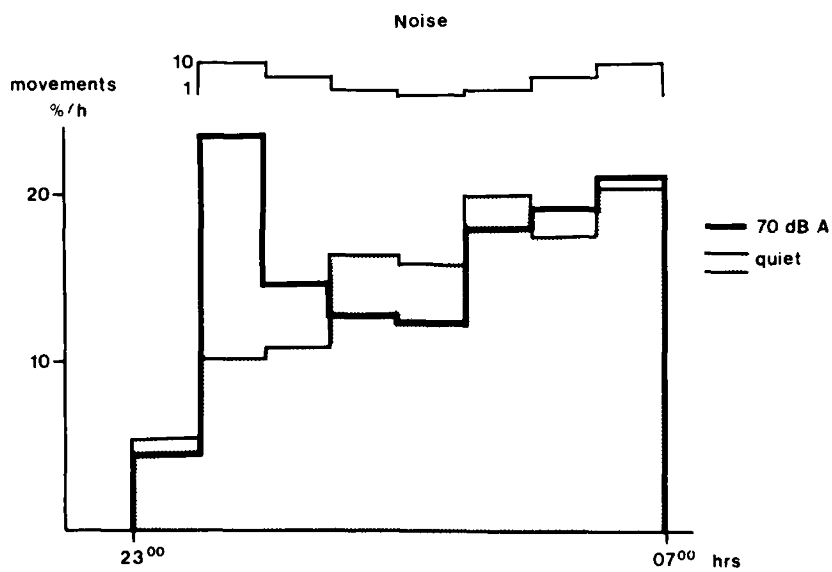

Figure 2. Relationship between body movements and intermittent noise.

Subjective sleep quality and mood. The results are shown in table 1 for the two lab experiments.

Table 1

Subjective sleep quality; mean values after nights with different noise exposures.

	Experiment 2			Experiment 1		
Noise	Quiet	Inter-mittent	Inter-mittent	Inter-mittent	Con-tinuous	Quiet
Peak dB(A)	--	60	70	80	--	--
Leq	31.1	34.5	42.5	51.4	51.4	34.0
N	12	12	12	6	6	6
Sleep quality	7.4	5.2*	4.7*	3.0xxx	6.8xx	8.2
Tired-alert	4.8	4.2	3.7	3.9	4.8	5.5
Irritated-friendly	7.2	6.1**	6.0**	6.7	6.3	6.8
Awakened	1.2	3.6**	6.3**	4.5xxx	2.5	1.5
SQI	12.1	9.0*	7.8*	2.4xxx	9.0	12.1

x Students' t-test, * Wilcoxon's test

Compared to reference nights, sleep quality variables decreased during nights with intermittent noise at all three noise levels. The difference between reference nights and nights with continuous noise was only significant for one variable (sleep quality).

In view of the results, the three measurements sleep quality, number of awakenings and tired-alert were combined into a sleep quality index (SQI). The difference in SQI between reference nights and nights with intermittent noise was significant as was the difference between the nights with different noises. The morning values for tired-alert were compared with those of the evening before. This is illustrated in figure 3. Subjects felt less tired after the reference night compared to the evening before. This was also the case for continuous noise and 60 dB(A) intermittent noise. After 70 and 80 dB(A) intermittent noise, the subjects felt more tired compared to the evening before.

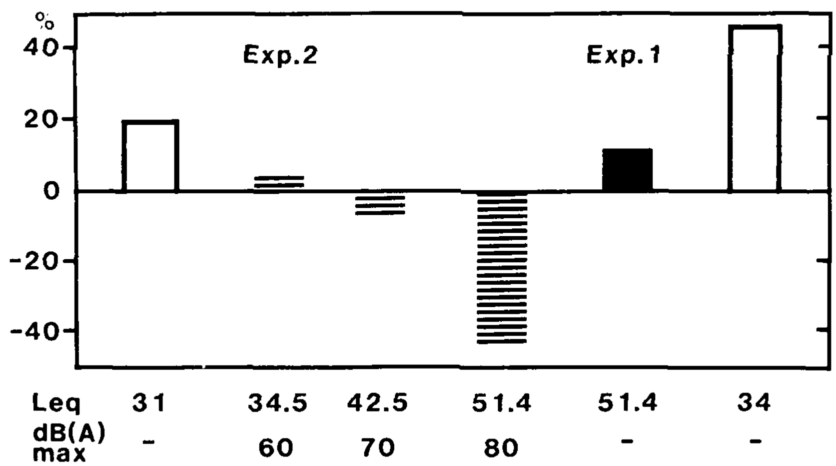

Figure 3. Tired-alert. Deviations in % from value in the evening.

The results from the mood questionnaire showed a tendency towards poorer values on all six variables after nights with intermittent noise but not after continuous noise in experiment 1.

In experiment 2 all mood variables except calmness were poorer after noisy nights compared to reference nights The differences were, however, only significant for extroversion. When morning values were compared to the values of the evening before for the different mood variables, values for pleasantness, calmness and control were found to be higher in the mornings after reference nights. After noisy nights no variables showed a higher morning value.

The relationship between SQI and noise levels is illustrated in figure 4. A poor relationship was found between SQI and Leq level (r = 0.51). When dB(A) max was related to SQI, a better dose-response relationship (r = 0.93) was found.

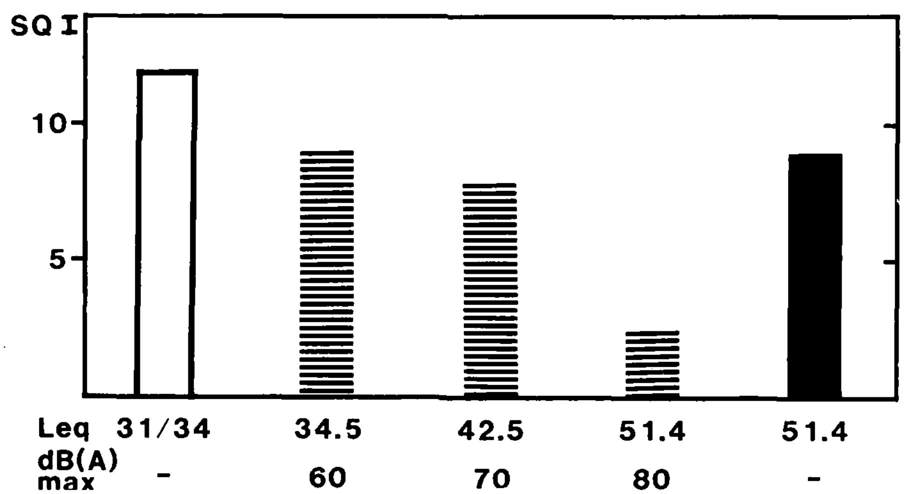

Figure 4. Relationship between SQI and noise level.

Performance test. The results from the performance test are shown in table table 2.

Table 2

Performance test; results on the first 10 min of the test as differences between evening and morning results.

	Experiment 2			Experiment 1		
Noise	Quiet	Inter-mittent	Inter-mittent	Inter-mittent	Con-tinuous	Quiet
Peak dB(A)	--	60	70	80	--	--
Leq	31.1	34.5	42.5	51.4	51.4	34.0
Reaction time						
speed (ms)	+31.4	+4.8	+8.7	-14.0	+37.7	+3.5
Total responses	+65.0	+19.7	+20.6	-23.7	+24.3	-0.8
Correct responses	+58.9	+16.9	+14.9	-17.3	+30.0	+0.3
Mistakes	-5.3	-2.7	-5.2	+6.3	+6.0	+1.2
% mistakes	+0.5	+0.4	+0.1	+0.5	+0.8	-0.3

+ = Better than evening test, - = Poorer than evening test

In experiment 1, the reaction time after the reference night was slightly better (+3.5) when the morning value was compared to the evening value. The mean reaction time after nights with intermittent noise was longer (-14.0) compared to the values from the previous evening, while the continuous noise had no adverse effect on the reaction time. A tendency towards poorer reaction time and a lower number of correct responses ($p < 0.10$) was found after nights with intermittent noise compared to nights with continuous noise.

In experiment 2 the improvement in performance over night was less after noisy nights (+4.8, +8.7 against +31.4 after the quiet nights) but the differences were not statistically significant.

Relation between movements, subjective variables and performance. The relationships (Spearmans' correlation coefficient) between different subjective and objective measures of sleep disturbances were analyzed for experiment 2, days 1-6.

All correlations between body movements and subjective variables went in the expected way. Significant correlations were found between movements and subjective awakenings, irritation and calmness. The number of mistakes and the percentages of mistakes on the performance test increased after nights with more movements, but the correlation coefficients were low.

SQI was positively correlated with the different mood variables, at significant levels for activation, extroversion, social orientation and pleasantness. SQI and sleep quality was also significantly correlated to the result of the performance test (total number of responses, correct responses, number of mistakes and mean reaction). The better the SQI, the better the test result. An increased number of awakenings tended to cause a poorer result on the performance test.

2. FIELD STUDY

MATERIAL AND METHODS

The field study was undertaken in an apartment building close to a road with frequent traffic, before and after installation of noise

insulating windows. Three persons, 23, 53 and 70 years of age participated in the study. They filled in the same sleep questionnaire as in the laboratory experiments before and after the window insulation. Bodymovements and noise exposure was recorded four nights during the same time periods.

The traffic noise levels were 35 dB(A) Leq before and 26 dB(A) after the noise insulation. Before the insulation there were 311 traffic noise events between 37-42 dB(A) against 93 afterwards, 158 events between 43-48 dB(A) before against 26 afterwards and 25 events between 49-54 events before against 0 after the noise insulation.

RESULTS

The number of movements registered per hour among the three test persons was between 9.6 and 19.2. A decrease in the number of movements was recorded after the window insulation for all three test persons.

As regards subjective sleep quality, test person 2 reported a clear improvement and test person 3 a slight improvement. Test person 1 reported a slight decrease in sleep quality (see table 3).

Table 3

Bed movements and sleep quality before and after insulation of windows for test persons 1-3. Figures in parenthesis indicate standard deviation of 4 measurements.

Subject	1		2		3	
	before	after	before	after	before	after
Movements/ sleep hour	19.2 (1.6)	12.1* (2.9)	13.4 (5.0)	5.6* (1.5)	9.6 (1.5)	6.0 (3.3)
SQI	15.7 (2.7)	13.3 (8.6)	-1.0 (0.8)	10.4* (3.2)	13.4 (5.6)	15.9 (0.8)

* $p < 0.05$ Wilcoxon rank sum test

CONCLUSIONS

The laboratory experiments have shown that the sleep quality index (SQI) is well related to the peak noise dose. Body movements frequently occurred immediately after a peak noise event and were significantly related to subjective awakenings and irritability in the morning. It is suggested that future sleep studies should incoperate measurements of SQI, performance and mood to elucidate after effects of noise-induced sleep disturbances. These measures, as well as body movements, allow for large-scale investigations in the field which are necessary in order to study long-term effects of environmental noise on sleep.

The results from the laboratory experiments and the field study show that traffic noise disturbs sleep (decreased sleep quality and mood and an increased *number of body movements*) at Leq-levels below 35 dB(A). Intermittent traffic noise has more adverse effects (decreased sleep quality and a tendency towards worse mood and performance) than a continuous traffic noise at the same Leq-level. Peak levels around 45 dB(A) indoors caused awakenings in the field study. The results underline the importance of peak noise levels rather than the total noise energy in Leq for sleep disturbance effects. Thus noise-reducing measures to protect against sleep disturbance effects should be focussed on a lowering of the loadest or most annoying noises.

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AN ESSAY IN EUROPEAN RESEARCH COLLABORATION: COMMON RESULTS FROM THE PROJECT ON TRAFFIC NOISE AND SLEEP IN THE HOME.

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INTRODUCTION

Up to the present, noise limits at night are based on findings from social surveys. Besides annoyance as a health hazard also health damaging physiological effects could be involved. Additional knowledge on the relation between health and noise-induced sleep disturbances is therefore desired to set these noise limits definitively. Recognizing a lack of experimental data on this relation, especially from field studies, the Commission of the European Communities has initiated an environmental research project to study influences of traffic noise on sleep and subsequent well-being of people at home, living in a noisy environment. This joint European study was carried out in four countries: France (FR), the Federal Republic of Germany (FRG), the Netherlands (NL) and the United Kingdom (UK). Results of separate teams can be found in a number of other papers [1-7]. Also some common results on certain aspects have been presented [8]. This paper gives a synthesis and an evaluation of all common results and strikes a balance of such a research collaboration.

DESIGN

Altogether 70 healthy and normally hearing subjects, men and women of different ages, slept both in relatively noisy and in relatively quiet conditions. For 52 subjects the normal condition was noisy (N), for 18 subjects it was quiet (Q). The experimental condition was realized by fitting double glazing (UK and NL), by using earplugs (FRG), by moving subjects to a quieter bedroom (FR) and by opening windows (FRG and NL). In most cases a N-Q-N design was used, but other condition sequences like N-Q and Q-N were examined too. Typical values for the number of nights per condition were 5 and 10. Thus the study included totally about 1000 nights.

Each night, acoustical and physiological signals were recorded and each morning and in some cases each evening subjective responses and performance measures were registered. All teams recorded the indoor sound level in dB(A), EEG, EOG, subjective sleep quality and reaction time (unprepared simple or four-choice) in the morning. Further registrations were: real sound (UK all nights and FR some nights), EMG (FR and NL), EKG (FR, NL and UK), respiration (NL), body motility (FRG and NL), signalled awakenings (UK), mood in the morning (NL), well-being by day, inquired in the evening (NL), four-choice serial reaction time, auditory short-term memory and the Wilkinson vigilance test in the morning (UK), and four-choice reaction time in the evening (FRG).

From all material registered, certain parameters were selected by the joint teams, to be generally analysed in terms of differences between the averages of measurements during the conditions noisy and quiet. Besides this joint analysis, other all-night and transient effects were analysed on an individual-team basis. Nonparametric statistics were used for all analyses.

COMMON CONCLUSIONS

Where possible, all team results on the basis of differences between condition averages per subject have been pooled to look for significant sign distributions. As common conclusions also those significant team results are considered, which are in the same direction for at least two teams, and which are not significantly in the opposite direction for any other team.

Thus the following common conclusions are stated:

1. On an average, subjects spent fewer minutes in REM-sleep during noisy nights (combined results of all teams, mean difference 6.5 minutes, $N = 67$ subjects, $p < 0.02$, Wilcoxon signed-ranks test).
2. After relatively noisy nights performance was affected adversely, appearing from increasing reaction time on the unprepared simple-

reaction time test (combined results of three teams, mean increase 12 ms, N = 27, $p<0.005$, Wilcoxon, see also [8d]). This conclusion is reinforced by a significant result of the fourth team: more errors in the four-choice reaction time test after noisy nights, compared to the evening before, and for some subgroups also not related to the evening before. Two teams found this increasing reaction time after noisy nights also separately.

3. After relatively noisy nights the subjective sleep quality was reduced (combined results of all teams, mean difference 7%, N = 62, $p<0.001$, Wilcoxon, see also [8d]). Two teams found this significant result also separately.

4. Wakefulness increased during relatively noisy nights (significant results of two teams separately).
5. Based on a minute-by-minute correlation analysis, the (mean) heart rate increased with increasing (equivalent) sound level (significant result of three teams).
6. The variability in heart rate was higher for noise events with higher peak sound levels (significant result of two teams).

To make sure that results of EEG analysis were comparable, the two different automatic sleep stage scoring systems used by three teams and the visual scorers of the fourth team analysed the same 41 nights. It was demonstrated that the percentage agreement between the two visual classifications was not better than the percentage agreement between the two automatic systems and visual scoring or between the two automatic systems mutually. All percentages were in the range of 70 - 80%, between the two automatic systems giving the highest average values.

DISCUSSION AND EVALUATION

Studying the influence of noise upon sleep, especially in the field, means looking for relatively small effects on parameters which may show large variations for various reasons.

With respect to this study, the following potential kinds of variation can be mentioned:

1. Variations between nights, between subjects and between teams, due to differences in actual noisy and quiet conditions. Table 1 illustrates this.

	FR	FRG		NL	UK
N	42-52	47*	43*	41-52	42-52
Q	27-44	40*	34*	35-43	41*
D	14- 2	7*	9*	14- 4	6*
		WINDOWS GROUP	EARPLUGS GROUP		

*: AVERAGED OVER SUBJECTS

Table 1. Variations between subjects and between teams in mean equivalent sound levels in dB(A) for noisy (N) and quiet (Q) conditions and in differences (D) between these condition averages.

Besides the noise-related variations, other important kinds are:

2. Variations from night to night within the same subject, due to normal physiological variability of parameters or to other environmental or somatic and psychic influences. The necessarily limited number of nights enhances these intra-individual variations.

3. Variations between subjects within a team, due to environmental effects (for example seasonal influences and noise dose by day), due to differences in design aspects (for example condition sequence), and due to social an personality factors.
   Only to a limited extent could some of these variations have been avoided. Recording about 250 nights per team with one equipment set takes about one year and hence allows seasonal variations. Using the same condition sequence, e.g. ABA, reinforces the statistical power, but having BAB as well helps to eliminate effects related to the experiment itself. Selection on social and personality factors again assists statistical strength, but gives results a limited generality.
4. Variations between teams, due to different design aspects noted in section 2, especially differences in realizing the experimental condition. Opening windows, wearing earplugs or moving subjects to another room can introduce other effects of various magnitude in relation to noise effects.

Summarizing, one can say that elimination of some of the sources of variation might have given more or more pronounced conclusive results. On the other hand, when still certain effects emerge, in spite of all these variations, the effects found must be considered to be of some importance and power. Looking at the common conclusions in that light, they are evaluated as follows:

1. The convincing conclusions on after-effects are a clear indication that noise has an adverse effect on the restorative function of sleep. Living in a noisy environment for years, people still have the feeling that they sleep worse in noise and are less refreshed in the morning.

as reflected in their performance.

This must be seen as a potential health effect.

2. Concerning the physiological conclusions, the most pronounced is the effect of noise on heart rate . Even after years of habituation to the noise situation, and similarly in relatively noisy and quiet conditions, noise events disturb the heart rate, more at higher peak levels.

   This compared to daily loads small, but clearly and constantly present, extra physiological load during the night should be indicated as a potential health effect. It is in contradiction with the principal meaning of the sleep: relaxation.

   The conclusion on EEG effects are less pronounced, although here too after years of exposition various signs of disorganization of the normal sleep pattern remain present. The decrease of REM sleep during noisy nights is a finding of interest, but difficult to interprete.

   As REM sleep is often associated with psychic recovery, it could be a possible health effect. But the trend was not the same for all teams and the meaning of REM sleep has not been proven beyond any doubt.

   Similar problems occur with findings on other sleep stages.

   Generally speaking one should conclude that sleep stage effects are still precarious indicators of sleep quality and health effects.

   On the other hand, the increase in stage W during relatively noisy nights must be seen as a disturbance of the wanted parasympathic activity of the organism and should be considered as a potential health effect.

An important question is : Do these potential health hazards result in

actual health damage? As already mentioned, the effects found are relatively small and well within normal adaptation ranges. But having relatively small extra physiological and psychological loads year after year could interact with other (larger) loads in daily life to precipitate a breakdown in health. A definite answer to this question can only be given by epidemiological studies on an appropriate scale. Studies of this kind are therefore strongly recommended.

From the common results no quantitative relations between noise measures and the potential health effects found could be deduced. As the actual health consequences need also further determination, no pronouncement upon noise limits based on sleep disturbances can be made yet. But this joint study gives clear indications on which features future experimental and epidemiological research should be focussed to set limits definitely: cardiovascular measures and after-effects. Another important aspect is to look at individual differences like personality factors and sensitivity to noise to determine certain risk groups.

In summary of this attempt at collaborative research the following conclusions are offered:

- An extensive field study like this requires much effort to develop partly novel experimental procedures and analysing methods, and to reach a sufficient common approach for all teams. One can hold different views whether the common approach was sufficient or not, but the collaborative experience and joint lessons learned in these matters are an important achievement in itself. As it becomes increasingly impossible to afford scattered and often duplicating

research efforts, national and international research collaboration will certainly grow.

- In spite of many sources of variation this study gives clear evidence that, with respect to health, noise has adverse influences on sleep and subsequent well-being, and points the way to further research.
- For definite, quantitative pronouncements on health consequences and on noise limits at night, especially epidemiological studies are desirable.

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DOES DOUBLE GLAZING REDUCE TRAFFIC NOISE DISTURBANCE DURING SLEEP ?

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INTRODUCTION

Noise caused by the passing traffic during the night, can be considered as unwanted disturbance of sleep. Most of the measures taken to reduce the sound, reduce only the sound level. The relation between the physical characteristics of sound and an individual's perception of it as **annoyance** is complex and unclear. Moreover, we can not obtain a direct measure of **annoyance** during sleep. The **annoyance** during sleep is manifested in the physiological responses to the sound stimuli and the quality of sleep perceived in the morning. Both may result in deterioration of functioning during wakefulness which is caused by noise disturbance during sleep.

The possible consequences of the psychophysiological disturbance to the general health and well-being can only be established by performing a long-term experimental study. A long-term study is not free of ethical and practical problems. Therefore, we selected a group of subjects who

were already exposed to traffic noise during sleep for a long period and who were studied in their home along a highway with high traffic density. These results are obtained under conditions of **1) normal sound level,** and **2) reduced sound level** by double glazing. **The results presented in this paper provide an evaluation of the effectiveness of double glazing in reducing disturbance or annoyance due to traffic noise.**

MATERIAL AND METHODS

A. General

An experimental sleep study in the homes of 12 subjects was done. The EEG, EOG, ECG, respiration and indoor sound level, were recorded for 10 nights each in the two conditions: namely **1: normal sound level,** and **2: reduced sound level.** The indoor sound levels were decreased by about 10 dB(A) by means of double glazing of the windows. This is a very common method of reducing traffic-noise in the homes.

B. Psychological measures

The **annoyance** caused by disturbance during sleep manifests itself in mood and sleep quality assessed by the subject. The Profile of Mood States (McNair et al., 1971) and the Amsterdam Sleep Quality Questionnaire (De Diana et al., 1975 and Visser et al., 1978) were used as quantitative measures of mood and sleep quality respectively. An unprepared Simple Reaction Time **(SRT)** in the morning was employed as a measure of performance. A questionnaire, providing subjective evaluation of :

1) tiredness during the day, and **2) psychological functioning during the day,** was administered in the evening.

C. Event-related Cardiac Response

The phasic cardiac disturbances due to noise were analysed by an **Event-related Cardiac Response (ECR)** technique. A peak in the continuous sound level signal was defined as an event if it was at least 10 dB(A) above L90 (considered as a background level).The peak should also be separated by at least 30 beats from other peaks of equal or lower peak level. The continuous sound level signal was digitized, at the moment of RR incidence in the ECG, along with the time interval between the two RR incidences. We grouped peaks in different classes of slope, duration and peak-level. The change in beat-by-beat heart-rate of 15 beats before and 15 beats after the peaks were averaged to obtain an **ECR.** The magnitude of cardiac response from this **ECR** was calculated as shown in Figure 1.

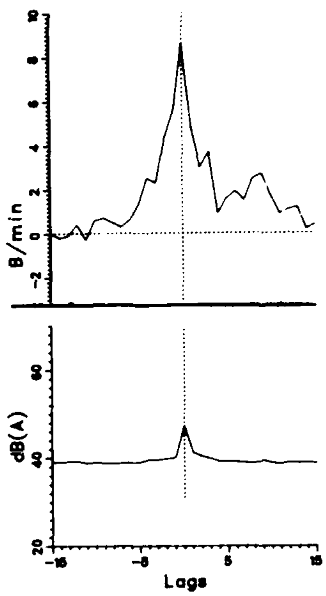


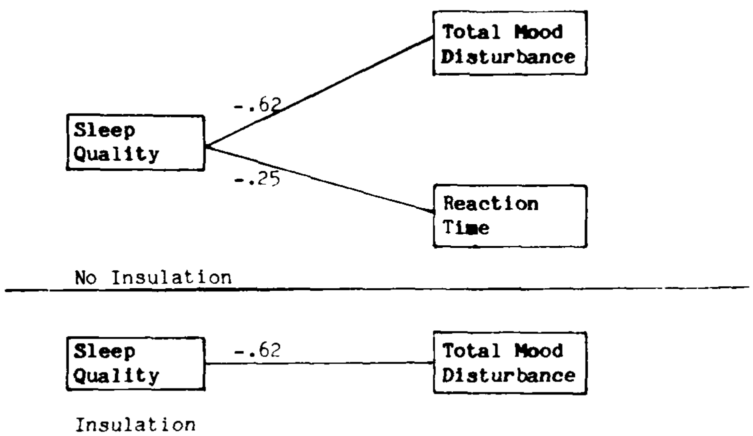
Figure 1. A plot of a typical **ECR** at the top and the corresponding averaged stimulus at the bottom from one night are shown. The vertical dotted line shows incidence of peaks. The **ECR** is averaged by calculating difference in beats per minute of each beat from a base-line beat which is 15 beats before the peak. Lags are in beats. The **ECR** and the averaged stimulus were obtained by averaging all peaks with a slope of more than 3dB(A) per sec.. The magnitude of the cardiac response was calculated as a difference between the maximum and the minimum of the **ECR** within the 4 beats of either side of peak.

RESULTS

A. Psychological Effects

Sleep and wakefulness are two interrelated states. Daily functioning is influenced by the quality of the sleep the night before, and the sleep quality is considered to be directly related to the restorative value of sleep. By means of a path analysis we can calculate the effects of the restorative value of sleep on daily functioning. In our case the daily functioning is measured by means of the Total Mood Disturbance and the Simple Reaction Time. The difference in the restorative effects thus estimated, is a measure of the efficacy of the insulation in reducing psychological disturbance or the **annoyance** due to noise. For this purpose we used the path analysis in two different conditions. The results are shown in figure 2.

Figure 2: Significant (p .05) path coefficients showing the relation between sleep quality and functioning in the morning for the two conditions.



These results are interpreted as follows. **During the nights without insulation, the quality of sleep is so low that both performance and mood are negatively effected. The installation of sound insulation is not effective enough to increase the restorative effects of sleep because we see that the improvement in the sleep quality is not sufficient to avoid negative effects on performance.**

B. Physiological Effects

These results established that the psychological effects of noise disturbance during sleep i.e the **annoyance** were not reduced by sound insulation, but we do not know whether the sound insulation helps to reduce physiologically measured sleep disturbances. For this purpose, we have to obtain direct measures of disturbance during sleep. The results on effects of noise on sleep stage parameters are already presented by Jurriens (1981). Moreover, from epidemiological studies on health and

noise, the prominence of cardiac disorders are often reported. We thus looked in detail into heart-rate disturbances due to noise. Cardiac and respiratory mechanisms are interrelated, therefore, results on effects of noise on respiration rate are also presented.

B.1 Respiratory Effects

The mean respiration rate was correlated with the Leq of sound level per minute. The results were:

- **The number of nights with significant ($p<.05$) correlations were higher with insulation (80%) than without insulation (70%).**

- Both number and level of positive correlations were not different from that of the negative correlations. This is due to the fact that an increase or decrease in respiration rate as response to the stimulus, depends on the phase relation between stimulus and the respiratory signal.

B.2 Cardiac Effects

The correlations between the mean sound level and the heart-rate measures per minute were positive in both conditions. But the number of nights with significant ($p<.05$) positive correlations were higher with insulation (84.7%) than without insulation (76.3%). The regression coefficients showed that an increase of 5 dB(A) in sound level amounted to an increase of:

- **a mean of 1.9 beats per minute**

- **a standard deviation of 2.96 beats per minute**

An ANOVA for repeated measures for difference between the two conditions revealed significantly ($p<.01$) higher correlations between heart-rate and Leq in the condition with the sound insulation than in the condition without the sound insulation. This means that effect of sound level on

heart rate was larger in the condition with sound insulation than in the condition without insulation.

Because the increase in the standard deviation of the heart rate is higher than the increase in the mean heart rate, we might say that the phasic mechanisms are involved in the cardiac disturbance during sleep. The phasic cardiac disturbances were analysed by employing the **Event-related Cardiac Response** method described earlier in this paper. Different regression coefficients between the magnitude of the cardiac response and the characteristics of peaks were calculated in each condition. The results were:

- The cardiac response increased at a rate of 0.43 beats per minute for an increase of slope of the peak by 1 dB(A) per second without insulation. **Moreover, there was an increase of 0.86 beats per minute per dB(A) per sec. with sound insulation.**
- There was a decrease of .215 beats per minute for one second increase in the duration of the peak without insulation. The sound insulation did not show any significant regression of the duration of a peak with the cardiac response.
- **The mean value of the cardiac response was 2.1 beats per minute with insulation and 1.95 beats per minute without insulation.**

These results clearly show that the phasic cardiac disturbances are not reduced by sound insulation. Thus, we have provided evidence that **the efficacy of the sound insulation in reducing physiological disturbances is totally absent.**

Both the psychological and the physiological results forced us to doubt the efficacy of the double glazing in reducing disturbance during sleep. We then ask: **What are the acoustic effects of double glazing ?** In next section, we present results on acoustic efficacy of insulation.

C. Acoustic Efficacy

For establishing the acoustic efficacy of the noise abatement measures, we have to establish the acoustic properties of the signal which are relevant to the physiological disturbance and which represent the passing vehicles. From the results on the cardiac disturbances, we know that the slope and the duration of the peaks are major disturbing factors. We compared the distribution of the number of peaks according to the slope and the duration of the peaks. 14 nights from both conditions were used for this comparison. These nights represent different conditions, viz. acoustics of the surface between the highway and the house, location of the home, high-way and traffic density. See Figures 3 and 4 for details. The sound insulation did not change the total number of peaks but it only changed the skewness of the distribution.

Figure 3: The average distribution of the number of peaks of 14 nights, according to the slope of the rising part of the peak. The resolution of the bin-width is 1 dB(A) per second. The broken line indicates sound insulation, while the continuous line shows the normal sound level condition.

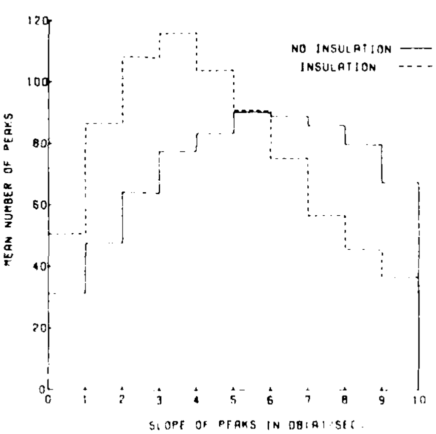
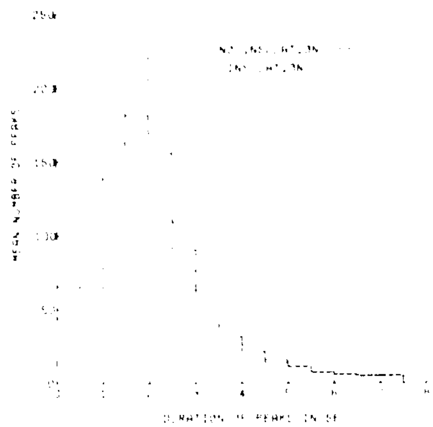


Figure 4: The distribution of the number of peaks of 14 nights, according to the duration of the peak. The resolution of the bin-width is 0.5 second .The broken lines indicate sound insulation, while the thick line shows the normal sound level condition.



Our definition of peaks assures that only sufficiently isolated peaks of relatively high amplitude are considered. But these peaks are not a true representation of the sound level characteristics of the passing vehicles. We estimated the range of the slope of the rising part and the duration of each peak which is related to the range of the speed of vehicles passing on the high-way. For this purpose, we utilized:

- distance of the house to the highway
- surface between the high-way and the homes
- attenuation with distance characteristics of the sound levels given by Alexandre et al.(1975).

The clusters obtained from the cross-tabulation matrices between the three variables: **1) level of the peak, 2) slope of the peak and 3) duration of the peak,** were also used (see Tulen et al., 1983, for details). This resulted in the following characteristics of the peaks in the continuous sound level which are dominant during the night and which are caused by passing vehicles:

- the slope of the rising part of peaks between 2.0 and 7.0 dB(A) per second.
   - the duration of peaks between 1.0 and 4.5 sec.
   - the corresponding peak levels were between 36 and 48 dB(A) with insulation and between 45 and 60 dB(A) without insulation.

There was no significant difference in the mean number of peaks between the two conditions. Moreover, there were significantly more peaks of shorter duration in the condition with the sound insulation. **The acoustic efficacy of sound insulation on sleep by double glazing is not shown.** It should be noted that the above characteristics do not represent all vehicles. Vehicles passing in parallel, or passing in the opposite direction were not included, because we were interested in temporally isolated peaks for the estimation of physiological responses. These results also support our method of estimating vehicle-related peaks.

The physiology of sleep has different ultradian and circadian characteristics. Therefore, the temporal distribution of peaks may also have an effect on the disturbance during sleep. We examined the temporal distribution of both the sound level and number of peaks. The results were:

- The number of peaks and the level of sound show a dip around the middle of the night. It corresponds, however, to an expected decrease of traffic-density in the middle of the night.
- The mean slope and duration of the peaks for each 10 min. period is constant over the nights and is similar in the two conditons.

The temporal distribution of the mean slope of the peaks, in the two conditions is shown in figures 5 and 6.

Figure 5: Mean slope of the peaks calculated per ten minutes is shown. The x-axis is divided in hours. The data were obtained from a typical night, recorded with sound insulation.

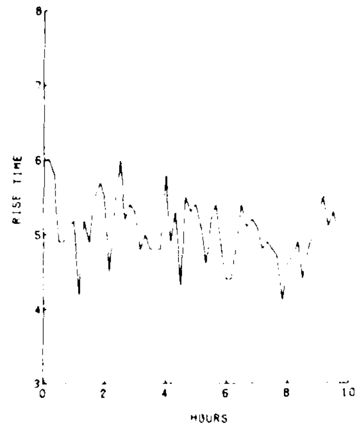


Figure 6: Mean slope of the peaks calculated per ten minutes is shown. The x-axis is divided in hours. The data were obtained from a typical night, recorded without sound insulation.

Thus, any acoustic efficacy of double glazing in reducing sleep disturbance is disclaimed by our results.

CONCLUSIONS

By comparing psychophysiological disturbances due to traffic noise, with and without insulation, we have presented a methodology which provides a detailed evaluation of the efficacy of double glazing. Insulation by double glazing does not help in:

1. increasing the sleep quality to such a level that performance on the following day is not negatively influenced;

2. reducing the cardiac and respiratory disturbance during sleep;

3. reducing the transient characteristics of traffic noise which are most disturbing.

We provided evidences that double glazing does not reduce measurable sleep disturbances due to traffic noise. Though our results did not give an evidence on effects of noise on general health, **the efficacy of sound-insulation measures should be evaluated thoroughly and similar to our methodology.**

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SLEEP DISTURBANCES BY ROAD TRAFFIC NOISE AS RECORDED IN THE HOME.

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The effects of nocturnal exposure to road traffic noise on sleep have been studied in numerous experiments. Most of these studies have been performed in laboratories. For a review see ref. (1) and references therein. A more recent approach has been to use recordings made on subjects sleeping in their usual environment with exposure to traffic noise (2-6). However, the effects of road traffic noise on the normal sleeping pattern, as reported by different groups, vary, especially with respect to effects on REM- and slow wave sleep. The aim of the present investigation is to study, in the subjects' own home environments, how the sleeping pattern is influenced by exposure to road traffic noise during different parts of the night.

MATERIAL AND METHODS

Scheme

The experiments were carried out in the subjects' own homes along quiet streets without nocturnal night traffic.

Noise exposure was realized by playing back traffic noise that has been recorded on magnetic tape. This design enables the combination of some positive features of field studies - only little habituation to the experimental environment is required - and laboratory studies - complete control over the noise exposure.

Three types of noise exposure were used in the present experiment: 20 truck passages (speed 70 km/h) with peak sound level 55dB(A) during the first 2.5 hours of the night (N1) (starting half an hour after lights out), in the middle of the night (N2) or during the last 2.5 hours of the night (N3). Within the 2.5 hour period the time interval between two truck passages was chosen at random between 2 and 13 min (average 7.5 min). The noise was frequency corrected to simulate the attenuation characteristics of an average dwelling. Between truck passages the noise level near the pillow was in average below 30 dB(A). An experimental series contained 12 recording nights within a 3-week period; 5 exposure nights and 7 quiet nights (Q). Weekend nights were avoided.The experimental program for each subject was designed as follows:

week 1: N - Q - Q - N1
week 2: Q - N2 - Q - N3
week 3: Q - N - Q - Q

The first two nights served habituation purposes, both to the experimental arrangements and the noise, and were excluded from analysis. Nights 3 and 12 served as reference nights. The sequence of exposure nights Ni (i=1,2,3) was permuted for the different series. The last exposure night was a repetition of one of the earlier nights Ni.

Subjects

The subjects were 7 paid volunteers, 3 couples and 1 male (partner not recorded), ranging in age from 25 to 29 years. Investigations on 2 more couples are in progress. They used no drugs, abstained from alcohol the days before recording nights and lived as routinely as possible. They went to bed and were awakened at their usual times.

Recordings

As physiological signals, 2 EEG derivatives (C4-A1 and C3-A2), EOG (E2-A1), submental EMG, ECG and body movements (accelerometer connected to the bed) were recorded for 2 subjects simultaneously, together with the sound level. After time division multiplexing in conjunction with pulse code modulation (PCM) these signals are recorded digitally on one track of a 4-track PCM recorder. The bandwidth of the system is 1.5-25 Hz. The fast EMG signals were rectified and slightly integrated before being processed by the PCM system. For analyzing purposes the tape recordings were played back for each subject on paper on a 8-channel ink-jet recorder.

This procedure was done at a tape speed 16 times the speed at recording.

In the morning, within half an hour after awakening, the subjects completed a questionnaire about sleep quality and a mood measurement questionnaire (7). In addition, the mood questionnaire was filled out around noon, at 4 o'clock p.m. and in the evening before bedtime. In the evening also a short questionnaire about their well-being during the day and tiredness at that moment was completed.

RESULTS AND DISCUSSION

Some preliminary results on the first 7 subjects are presented in this paper. Sleep stages are scored visually according to international standards (8). For each subject and noise condition the duration for each sleep stage is compared to the average of the quiet reference nights. The significance of the found difference is tested for the whole group with Wilcoxon's signed rank sum test for matched pairs (9). The results are summarized in table 1.

Table 1. Group averages (SEM in brackets) for the reference nights $\bar{Q}$, deviations from the reference nights for the three noise conditions $(\overline{Ni-Q})$ and Wilcoxon's T for 4 male and 3 female adults (25-29 years old).

Stage	$\bar{Q}$	$(\overline{Ni-Q})$			Wilcoxon's T		
		N1	N2	N3	N1	N2	N3
TSW	2.7(1.3)	14(9)	5(3)	1.0(1.2)	0	0	6.5
%SW	0.7(0.4)	4(3)	1.4(0.7)	0.3(0.3)	0	0	6
TS1	20(5)	-4(4)	4(4)	-1(4)	6	3	12
%S1	4.9(1.3)	-0.8(0.8)	1.2(0.6)	0.3(1.2)	7	2	12.5
TS2	218(11)	5(12)	16(4)	-3(10)	9	0	14
%S2	55(2)	5(2)	4.1(0.5)	3(3)	1	0	8
TS3+4	55(9)	1(5)	-6(4)	-8(7)	11	3	6
%S3+4	14(2)	1.5(1.7)	-1.3(1.2)	-1.2(1.8)	6	4	7
TSR	100(10)	-25(8)	-14(4)	-13(14)	0	0	9
%SR	24.8(1.9)	-4.9(1.2)	-3.4(0.8)	-1(3)	0	0	8
L3	17(3)	2(4)	-6(2)	-0.2(1.7)	8	1	8.5
LR	79(8)	5(16)	9(16)	-9(7)	9	7	7
TST	399(16)	-31(16)	-2(10)	-27(11)			

When Wilcoxon's T = 0 an effect of the noise condition different from zero may be suspected although the material is too small to draw any definite conclusions. The most consistent trends towards better rated sleep were observed when the subjects were exposed in the beginning and the middle of the night; the durations of awake and stage [illegible] increase whereas the duration of stage REM decreased. No effects of the conditions on slow wave sleep were observed. Exposure in the latter part of the night did not cause any observable trends.

It is too early for any speculations with respect to [illegible] findings. Furtner analysis of the total material will also include the barycentre and other distribution parameters in order to study the time development over the night for each sleep stage. The effects of the different noise exposures on the ECG, body movements, subjectively rated sleep quality and mood will be reported in a future paper.

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EFFECTS OF PEAKS OF TRAFFIC NOISE DURING SLEEP ON ECG AND EEG

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INTRODUCTION

At the Third International Congress on Noise as a Public Health Problem a project was described in which records of physiology during sleep, performance during the day, and subjective report of sleep quality were taken from people in homes bordering busy suburban arterial roads (Wilkinson et al., 1980). The effects of this traffic noise on the quality of sleep were investigated by introducing double glazing in the bedroom windows for one week and comparing records with those obtained under normal high noise conditions during weeks before and after the experimental period. The main purpose of the previous paper was to report the effects of the sound attenuation on performance the next day. A subsequent publication (Wilkinson and Campbell, in press) has reported the effects of the double glazing on sleeping physiology taken over the whole night. The present paper will concentrate also on the physiological data, but will present an interim report on analyses now in progress to examine the effects of individual peaks of traffic noise upon sleep as reflected in the physiological records of EEG, EOG, and ECG during sleep.

A more detailed description of the general method employed in this research may be found in two previous reports (Wilkinson, 1981; Wilkinson and Campbell, in press).

MATERIAL AND METHOD

Analysis of peak effects on ECG

The ECG was recorded during the night time sleep of 11 subjects under conditions of normal traffic noise (Noise) and also under the same conditions but with double glazing in the bedroom window (Quiet) which produced a 5.8 dB(A) attenuation of the noise. At the same time a continuous record of the noise level was taken on a parallel channel of the same tape recorder. The analysis is concerned with the effect of traffic noise peaks of various levels upon the Heart Rate (HR).

The data-bearing tape was replayed offline with the noise level channel connected to the A/D interface of an Eclipse S200 computer. The noise level was sampled at each heart beat. The ECG was derived from a parallel track of the tape recorder and fed to the digital input of the computer through a detector circuit which converted each QRS complex into a TTL-compatible square wave. As each heart beat pulse arrived the computer sampled the noise level. This record was subsequently scanned for the presence of peaks corresponding to the passage of vehicles. Peaks were detected within 10 ranges 3dB(A) wide from a low level usually of 36 dB(A). A peak was rejected if a comparable peak (within 3 dB(A)) or higher peak occurred within a period 32 sec before it or 12 sec after it. This excluded any nearby individual peaks and also any smaller peaks on the slopes of the larger peaks, thus ensuring that only isolated peaks with sharp rise and fall times were accepted. Each time a peak was found the computer stored the values of the 8 inter-heartbeat intervals before and the 8 after the peak. These values were then stored in one of 10 16-item bins according to the dB(A) range into which the peak fell. The contents of the 16-item bins were then averaged within each of the ranges to give an overall profile of the pattern of heart rate intervals before and after peaks in each range. The heartbeat interval records were then converted into heart rate in terms of beats per minute.

For the purposes of this interim report, and in an attempt to provide an uncomplicated indication of the influence of peak noise level on heart rate, the physiological response to the higher half of the noise peaks is compared with that to the lower half. To achieve this the 3 dB(A) ranges were divided for each subject into upper and lower 50 percentile peak levels in such a way as to give approximately equal numbers of traffic noise peaks in each half. Averages for each half were then obtained by averaging the 16-item bins of the ranges concerned. It should be noted that, as there were fewer peaks contributing to the ranges at the extremes of the distribution of noise peaks level, this procedure tended to emphasise the contribution of the peaks at these extremes.

Analysis of peak effects on EEG and EOG

The EEG and EOG records were passed through hardware analysers (see

Campbell and Wilkinson, 1981, for details) which provided TTL-compatible outputs whenever Alpha, Spindle, Delta, or Rapid Eye Movement patterns were present above arbitrary thresholds. These outputs were sampled at approximately 1-sec intervals through the night from the prerecorded analogue tape. At the same times and from from a parallel channel of the tape samples of noise level were fed to the A/D input of the computer. As with the ECG analysis the computer scanned the noise record for peaks within 10 ranges, each 3 dB(A) wide. Having detected a peak the computer stored counts of Alpha, Spindle, Delta, or Rapid Eye Movement (REM) for 7 '1-sec' samples before the peak, for the peak itself, and for 8 samples after. These samples were then averaged over all peaks in the range concerned, and then averaged, within each range, over all subjects separately for Noise and Quiet nights. Finally, again for the purpose of this interim report, these averages were collapsed into two ranges of noise level above and below what was roughly the halfway point in the distribution of noise peak levels, 54 dB(A).

RESULTS

Electrocardiogram

ECG response rates before and after the peak are shown in Figure 1 averaged over all subjects. The average curve for Noise and Quiet nights combined is given, and also that for Noise and Quiet nights separately. Three main trends may be noted. First, collapsing over Noise and Quiet nights (the full line in Figure 1) there was more variability in heart rate both before and after the peak for the higher than for the lower half of the noise peaks ($P < .05$). This was true whether or not double glazing had been installed. Second, there was an increase in heart rate over the first three heart beats after the peak as compared with heart rate over the three beats before the peak ($P < .01$). Third, heart rate variability after the peak was greater than that before when the data were collapsed over Noise and Quiet nights and High and Low peaks (full line, bottom set of traces). Fourth, heart rate was higher during Quiet than during Noise nights (compare dotted with dashed lines). Neither of the two last-named results quite reached significance. In commentary, the most important result here is that noise peaks, and particularly high ones as compared with low ones, appear to increase heart rate varability.

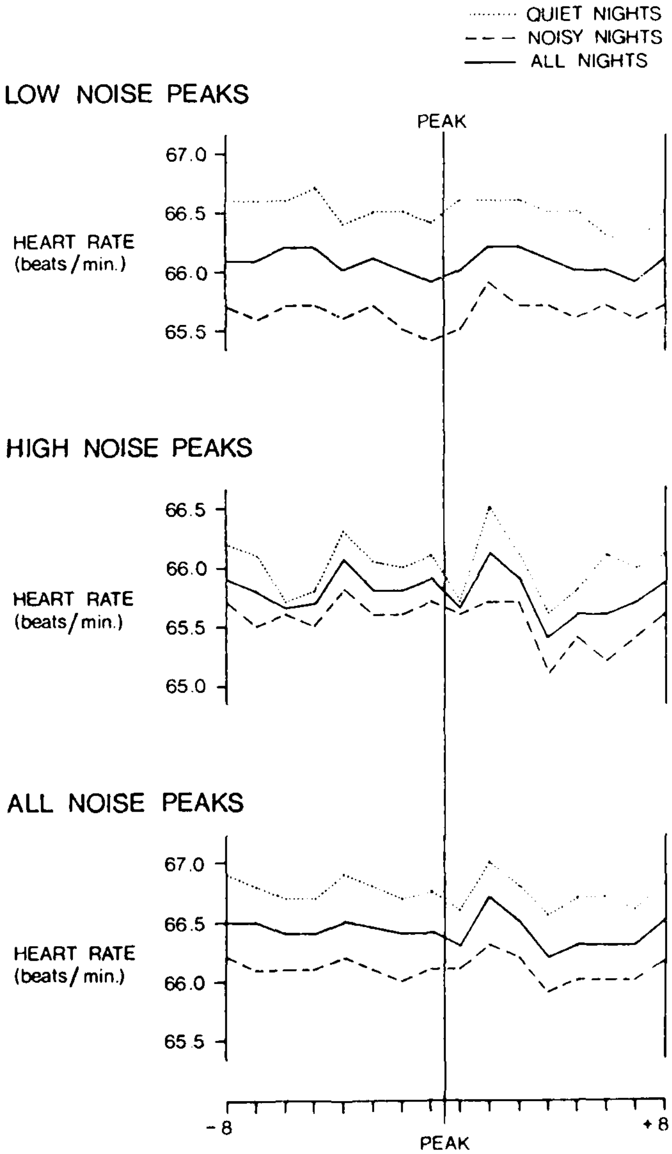

Fig. 1 Effects of noise peaks on heart rate.

Electroencephalogram and electrooculogram

The results of the analysis of EEG and EOG records are shown in Figure 2. Rapid eye movements (REM) appeared to be depressed by peaks and rose substantially after them, irrespective of peak level or whether the night was a Noise or Quiet one. Delta frequencies showed no overall changes in level after the peak as compared with before. Instead peaks at all levels, and for both Noise and Quiet nights, were associated with a transient increase in delta at and around the peak point. This may reflect the occurrence of K complexes (brief bursts of Delta-like responses evoked by exogenous or endogenous sensory stimuli). The same phenomena appeared to a lesser extent in Alpha frequencies. Spindles were little affected by noise peaks.

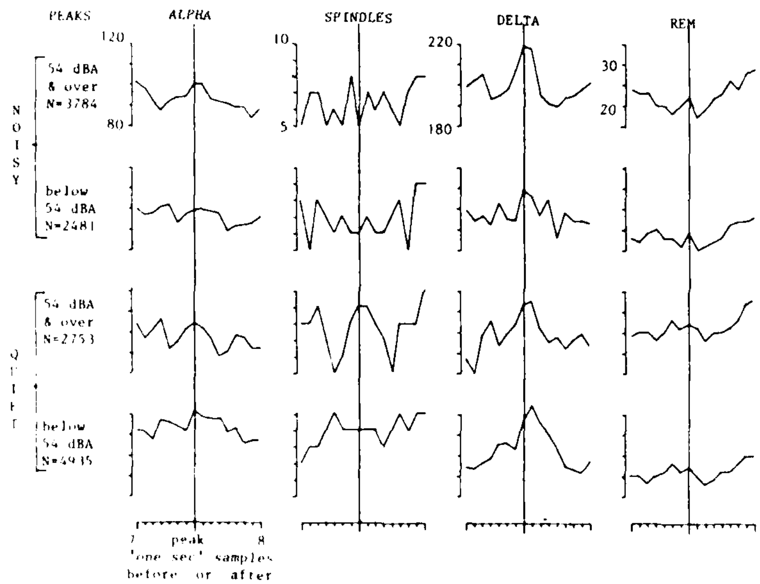

Fig. 2 Effect of noise peaks on EEG and REM parameters, separately for Noise and Quiet nights.
Note: scales are in units of 100 x % of all samples in which the features alpha, spindles, delta and REM were present.

DISCUSSION

In general, the present analysis suggests considerable adaptation among these residents to the individual peaks of traffic noise. Although there were some effects to be observed on heart rate and its variability, the extent of these changes was within the range of 2 beats per minute when averaged over all subjects. It seems unlikely that changes in heart rate as small as this could pose any threat to health.

With regard to the EEG and EOG records, a previous analysis of these data which considered the total activity in alpha, spindle, or delta frequencies over the whole night, suggested that the amount of delta activity was reduced on Noise as compared with Quiet nights (Wilkinson, 1981; Wilkinson and Campbell, in press). This provides some basis for expecting that individual peaks of noise should be found to reduce the level of any delta activity they may impinge upon, and this more so with increased level of the noise peak. No such effect has emerged from the present peak analysis. The only change in delta has been an increase at the point of the peak, suggesting the presence of a K complex in the EEG provoked by the climax of the sound. Thus, in terms of the frequency of delta waves (the most likely index of quality of sleep in the EEG), the subjects appear to have adapted to individual peaks of traffic noise to a considerable extent. That they still show an overall depression of delta over the night during the normally noisy nights as compared with the quiet ones may be due to the almost continuous succession of peaks in the noisy condition preventing them from reaching as deep a stage of sleep as was possible with double glazing. Rapid Eye Movements during sleep did, however, show a uniform increase in the four independent sets of data shown in Figure 2. While this is one of the clearer indications of an impact of individual peaks of noise

on sleep in the present data, it is difficult to interpret, for as yet it is unclear whether an increase in REM represents an improvement or deterioration in quality of sleep. If noise peaks are thought to disrupt sleep, then the rise in REM which has followed them in the present data may constitute evidence that REM represents a more disturbed state of sleep.

Finally it should be noted that the present sample of people was probably a relatively insensitive one as regards the vulnerability of their sleep to noise. It was decided at the outset of the project that no people should be included whose health was at all suspect, or who took sleeping pills. Thus the very people whose sleep might be most at risk through noise, the ill and the naturally poor sleepers, were excluded. It is hoped that further work along the lines of the present study may be able to make a special examination of groups of the population like these, who may be more exposed than most to the danger which excessive traffic noise presents to the health of the community through its impact on sleep.

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HEART RATE REACTIVITY TO AIRCRAFT NOISE AFTER A LONG TERM EXPOSURE

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INTRODUCTION

A major question about the effects of noise is the problem of the long term exposure. In order to evaluate this long term noise, researchers generally carry out longitudinal studies on noise-exposed people, who are staying on this noisy place. We should not forget to take into account people who are moving in another place, for environmental or other reasons.

In 1975-76, our team has performed a study about the effects of aircraft noise on the sleep quality, on 40 men, living near Paris Roissy Airport (1). At this time all subjects lived there for a minimum of one year and they were therefore already exposed to noise for quite a long time.

In 1982 we have recorded again the sleep of 14 out of these 40 subjects of the initial sample. From 1976 to 1982, 22 subjects have moved out and the 4 remaining subjects refused to participate again.

The aim of this longitudinal research is to test the existence of a physiological habituation, and if any, to evaluate its amplitude by comparing, within the same subjects, the heart rate response to aircraft noise, between 1975 and 1982.

METHODS

The same recording methodology was used in both experiments. A medical survey is made to check any major health or physiological problem likely to have occured since the first 1975-76 phase, as well as in family or professional life.

Each subject was recorded at home during four consecutive nights. They were habituated to wearing electrodes for three nights the week before. Every night, one hour before bedtime, a technician applied the electrodes (derivations EEG; $C_z\,O_2 - F_z\,O_1$, 2 EOG, EMG, ECG), calibrated, and turned on the equipment. Upon the subject's awakening, the technician removed the electrodes, turned off the equipment and gave the subject a brief questionnaire about sleep quality.

Physiological polygraph records were usually reduced, according to RECHTSCHAFFEN and KALES methods (2) with epochs of 1-minute duration. The ambient noise was recorded in dB(A) the whole night, with 2 samples per second. The analysis of the acoustic signal is made in the same way as for the first phase (1). The analysis of the Heart Rate (HR) signal is facilitated by passage in a cardiotachometer.

RESULTS

In a first step, we compare acoustic characteristics of nights during the 1st and 2nd phases. Table 1 shows the number of flights per night and their distribution. In 1982, half nights were concerned with 5 flights or less, therefore the conditions were appreciably changed with respect to 1976.

Number of flights per night		0-5	6-10	11-15	16-20	21-35	Number of nights
% of nights	1975	12	41	26	12	9	160
	1982	51.5	37.5	5	3	3	64

Table 1 - Number of flights per night (during the recording time).

The distribution of noise peak levels is shown on Table 2. We find only a few variations between 1975 and 1982. In 1982 however, peak values are somewhat higher than in 1975; this results from the fact that the subjects from the final sample live a little closer to the runway, as an average, than the 1975 initial sample.

Peak levels in dB(A)		35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	Number of noises	Mean values
% of noises	1975	19	9.3	19.[illegible]	14	19.4	9.6	10.5	5	3.8		1695	54.5 dB(A)
	1982	0.4	11	8.7	20.9	13.7	18.6	12.[illegible]	9.7	1.8		393	57.3 dB(A)

Table 2 - Peak noise levels distribution;

Noise distribution was controlled in function of sleep depth stages, and we determined the very same noises in 1976 and 1983 (see Table 3), thus demonstrating that slight evolutions in total sleep time and bedtime do not have any influence.

Sleep stages where noises occur		REM sleep	Stages 3+4	Stages 1+2	Stage 0	Nb of noises
% of noises	1975	18	16	57	9	1695
	1982	17	18	51	14	393

Table 3 - Percentage of noises per sleep stages.

The analysis concerns HR variations, from an ECG paper graph and from the graphic signal after cardiotachometer reading. Before every noise occurs, we measure the HR-value, and we consider HR variations during this period of noise emergence plus 30 seconds. The HR response to noises may

take on 4 processes :

- reaction 0 : no discernable reaction;
- regularization : arhythmia decreases and the HR-value regularizes;
- ON-OFF reaction : a physical reaction can be perceived at noise emergence, then when the noise stops;
- positive reaction : the HR-value varies according to a more or less similar pattern at acoustical signature, with real acceleration, then discrete deceleration.

The whole is visually coded by a trained observer.

The treatment consists in making a before-after comparison (1975/6 - 1982) of the average HR heart reactivity, all EEG stages undistinguished, all subjects undistinguished, and then in detailing. The HR reactivity is determined, as in prior works by MUZET (3), as a number of heartbeats/minute according to the noise parameters values.

- <u>Evolution of ECG reaction types to noise according to the exposure time</u>

We only consider 3 types of reactions and we collect under the term of phasic reactions the ON-OFF reactions and regularizations, which only scarcely occur. Comparing the distribution of these 3 types of reactions shows - Fig.1 - very slight variations in the course of time. In 1982, the percentage of reactions 0 is slightly higher than in 1976. The frequence of positive reactions remains stable with time, however showing a light decrease in reactions at highest peak levels in 1982. The frequence of phasic reactions somewhat decreases in 1982, in connection with increase in reactions 0. This concerns a trend for variations which are not statistically significant. In addition, it is quite complex to define a threshold in noise peak level; it can be noticed an increase in HR reactions above 65 dB(A).

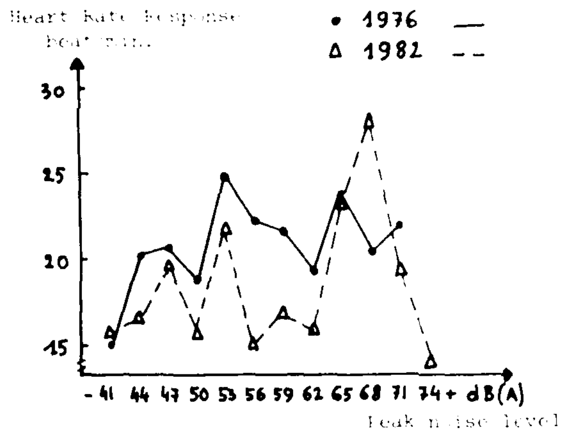

Fig.1 - Comparison of ECG effect types distribution between the both phases of experiments

- Evolution of reaction amplitude according to the peak level, with exposure time

We calculate the average value of the maximal amplitude of HR reactions for each noise, then we determine the variation of this amplitude according to the peak level of noises (Fig.2) for each of the both investigation phases.

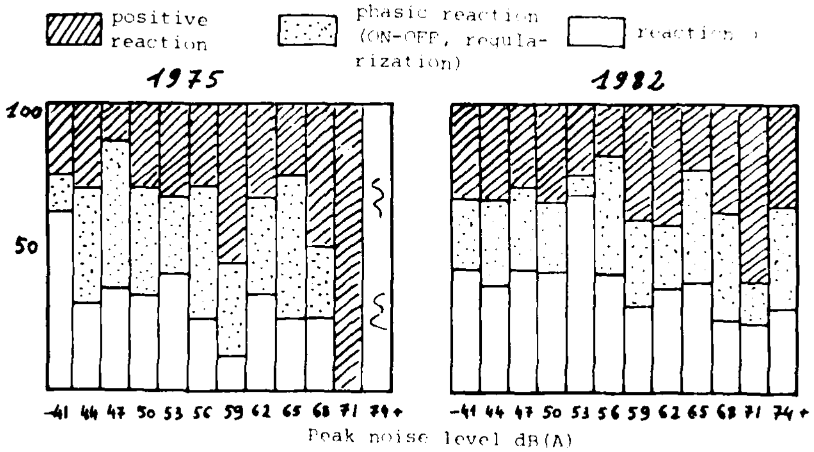

Fig.2 - Comparison of the ECG reaction amplitude in function of peak noise between the 2 experiment phases.

We observe that, with respect to the lowest peak levels, the HR reactivity values are becoming lower in 1982. The decrease in reaction amplitude is lower than 5 heartbeats/minute and, on the whole, is not statistically significant. The observed variation arises from a small sub-group of subjects, who showed a strong reactivity in 1976, then have got habituated. The HR reactivity becomes, in both phases of the study, more distinct from 62 dB(A) in peak value.

DISCUSSIONS AND CONCLUSION

Our results confirm those obtained in laboratory during short-time experiments performed by MUZET (4), showing no decrease in noise response amplitude after a two-week noise exposure.

Our results also confirm those of European joint research works (5) (6) (7) which investigated heart frequence reactivity to isolated noises after several years of exposure of subjects to traffic noise : these experiments demonstrated that HR is positively correlated with noise on the basic time of 1 minute.

This lack of habituation of the phasic cardiovascular responses to isolated noises during sleep may possibly be related to experimental data from JACOBS and his collaborators (8) who showed that cells in the serotonergic Raphe Dorsalis Nucleus (RD) fail to habituate in response to auditory or visual stimuli. The excitatory responses to the stimulations persist during sleep and are independent of behavioral arousal which habituates together with the responses of cells in the classical reticular formation.

Our results can be compared with those of RATTIG (9) regarding aircraft noise exposure during daytime. The author concludes that "vegetative noise responsiveness was not correlated with noise exposure level and subjective complaint behaviour, but was correlated with vegetative respon-

siveness to the different ongoing activities".

However, our conclusions are somewhat influenced by a bias : the number of noises per night is lower in 1982 than in 1976. We know that, the lower the number of noises is, the higher the response probability is : this was demonstrated by MUZET (10), and GRIEFAHN pointed out that the time interval between 2 noises is an important variable, since the waking probability is maximal during a 40-minute interval (11).

We conclude, in spite of this experimental difficulty, that there is practically no habituation of HR reactivity after a 6-year exposure to aircraft noises by night and, although people are subjectively rather well adapted, the physiological effect of noise persists.

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BENZODIAZEPINE EFFECTS ON AROUSAL THRESHOLD DURING SLEEP

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INTRODUCTION

Though objective EEG arousal data have indicated no significant difference between good and poor sleepers in auditory arousal threshold from sleep (Johnson, Church, Seales, and Rossiter 1979), poor sleepers invariably report that they are "light sleepers" and are easily awakened by noises. These poor sleepers also report difficulty in returning to sleep once awakened. Benzodiazepine sedative-hypnotics, when given to insomniacs, decrease sleep latency, awake time after sleep onset, number of body movements, and the number of nocturnal awakenings, as well as producing subjective reports of having slept more "deeply" and "restfully". These subjective reports of "deeper" sleep occur even though EEG recordings indicate a benzodiazepine-related decrease in deep sleep, stage 4.

Are there objective data to support this subjective report of "deeper" sleep? If there is an increase in arousal threshold, is it related to time post drug ingestion or to

stage of sleep? Is there a difference in effects on arousal threshold over the night between a hypnotic with a long acting metabolite, half-life of 24-100 hours, and a short acting benzodiazepine having a half-life of 2-3 hours? This paper will review work from our laboratory relevant to these questions.

METHOD

STUDY 1. FLURAZEPAM:

In our initial study we investigated the effects of flurazepam, 30 mg, on the auditory arousal threshold of 12 male poor sleepers (sleep onset insomniacs, mean age 21.3 ± 1.0 years) selected on the basis of subjective complaints of poor sleep and EEG criteria of sleep latencies greater than 30 minutes on two consecutive screening nights (Johnson, et al 1979). After the 2 screening nights, all 12 poor sleepers received placebo for 7 baseline nights (study nights 1-7). Then 6 subjects received flurazepam 30 mg for 10 additional nights (study nights 8-17), and 6 continued to receive a placebo for the 10 nights. Except for the first two treatment nights, subjects slept in the laboratory on each study night. Lights out was at 1000 h and wake up was at 0530 h. Medication was given 15 minutes before lights out. EEG sleep activity was recorded according to standard criteria (Rechtschaffen & Kales 1968). Only the arousal data are to be discussed in this paper.

An ascending series of stimulus tones was employed to obtain arousal thresholds. The stimuli were 1,000 Hz, 2 sec. tones delivered at 30 sec. intervals, through a speaker placed 46 cm above the subject's head. Before he was instructed to

"go to sleep", awake auditory thresholds were determined on each arousal night. The awake auditory threshold varied between 35-38 dB (SPL re 0.0002 dynes/cm^2) for all subjects. The background noise level varied from 32-34dB. During sleep, tones began at 35dB and were increased in approximately 5dB steps until the subject pressed a signal button three times and said, "I'm awake". Arousal thresholds were obtained during: (1) first stage 2, (2) first stage 4, (3) second REM period, (4) stage 2 following second REM, and (5) at 0530 h, the time of the morning arousal. Each sleep stage had to be firmly established for a period of at least 3-5 minutes for a stimulus to be given. At least 30 minutes of uninterrupted sleep preceded each arousal except for arousal 1 where tones started 3-5 minutes following sleep onset (stage 2). Arousal tones were not given within 5 minutes of a body movement even when the movement did not change the sleep stage. The above schedule was followed on baseline study nights 1 and 5 and on nights 11 and 15 (treatment nights). Arousal threshold data were also collected on the first of the 3 follow-up nights, study night 18. After being aroused from sleep, the subject was told (via an intercom) to go back to sleep. The sleep latency was the time interval between this verbal command and the first sleep spindle, K-complex (stage 2), or REM epoch.

RESULTS

The flurazepam and placebo groups did not differ significantly in arousal threshold on any of the comparisons during placebo nights. The average arousal threshold for the subjects who later received flurazepam was 76 + 16 dB, and for

those who continued to receive placebo capsules, 75 ± 14dB. Since there were no between-night effects for baseline study nights 1 and 5 and for treatment study nights 11 and 15, the data were combined (i.e., mean of 1 + 5 and 11 + 15) to examine placebo-flurazepam group differences. The average arousal threshold over the night for the flurazepam group (81 ± 22dB) was higher than for the placebo group (71 ± 17dB) but not significantly, $t(10) = 1.14$.

Examination of our data from sleep stage arousals within the night indicated a time course effect. There was a gradual rise in arousal threshold during the first 2 hours post-administration and then a decrease for the remainder of the night (Fig. 1). To examine this time course, a stage-by-stage comparison was done. Although the arousal threshold was higher for the stage 4, REM, and second stage 2 arousals, the t-test indicated that only the mean stage 4 arousal threshold ($\bar{x}$ = 99 ± 25dB) for the flurazepam group was significantly higher than for the placebo group's mean arousal threshold ($\bar{x}$ = 73 ± 13dB), $t(10) = 2.30$, $p < 0.025$ (one tailed). The mean time since pill administration to the stage 4 arousal was 101 ± 45 minutes. The increase in arousal threshold for the flurazepam subjects was present on study night 11 and did not further increase (or decrease) on subsequent drug nights.

No significant differences between the flurazepam and placebo groups were observed during the follow-up nights. On follow-up, the flurazepam group arousal thresholds and sleep latencies returned to approximate baseline levels.

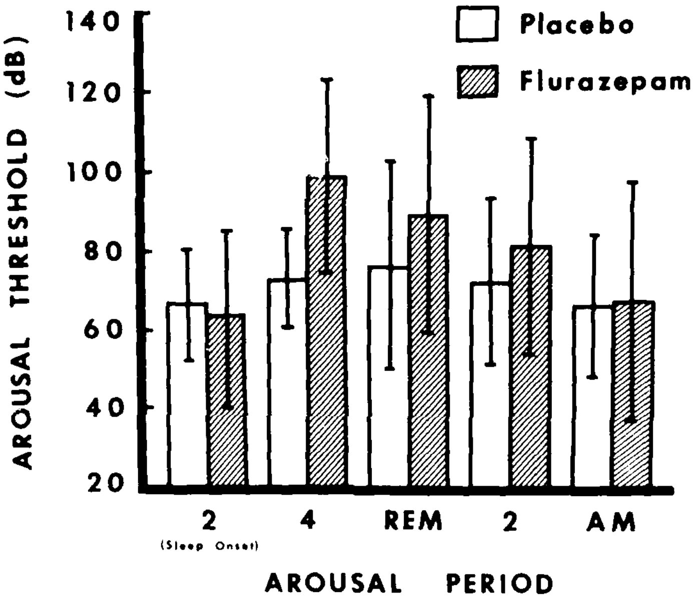

Fig. 1 - Flurazepam and placebo group mean (± SD) auditory arousal thresholds by arousal periods (placed in chronological order).

Study 2. TRIAZOLAM:

Triazolam is a short acting benzodiazepine hypnotic with a reported 2-3 hour half-life. In this study 20 male poor sleepers (mean age 21 ± 2.37 years), were recorded during one screening night, and three consecutive placebo-baseline nights. Following the placebo-baseline nights, 10 subjects continued to receive the placebo for 6 nights and 10 received triazolam, 0.5 mg, for 6 nights in a double blind paradigm. After the 6 treatment nights, all subjects received a placebo for 2 withdrawal nights. The selection criteria for poor sleepers and nighttime recording procedures were the same as in study 1, (see Spinweber & Johnson 1982).

While the arousal procedure was similar to that in study 1, there were some differences. The threshold for arousal from sleep was obtained on 3 recording nights: night 3 (placebo-baseline), night 6 (second treatment night), and night 8 (fourth treatment night). Tones were 2 sec. long and occurred at 16 sec. intervals. Arousals were scheduled to reveal the time course of action of triazolam and were performed six times: (1) during the first stage 2 sleep, 5 minutes after the sleep onset; (2) during the first SWS (Stage 3 or stage 4) at least 20 minutes after the return to sleep following the first arousal; (3) in stage 2, 150-210 minutes after lights out (0030-0130 h); (4) in stage 2, 270-330 minutes after lights out (0230-0330 h); (5) in stage 2, 370-430 minutes after lights out (0410-0510 h); (6) the morning arousal, at 0530 h.

The criteria which had to be met to initiate arousal procedures were similar to those of study 1. The dB level for the highest tone presented and the latency (in minutes) from the time of awakening to the return to sleep were recorded.

RESULTS

Arousal threshold was significantly higher during treatment for triazolam subjects at the time of the first [$t(18) = 2.44$, $p < 0.025$], second [$t(16) = 5.65$, $p < 0.0005$], and third [$t(17) = 2.93$, $p < 0.005$] arousals (Fig. 2). (Not all subjects met the criteria for all arousals, thus altering the degrees of freedom reported above).

Within-group analyses revealed that triazolam significantly raised arousal threshold for the SWS arousal [$t(9)$

3.40, $p < 0.005$]; it was also found that placebo group subjects became more sensitive to the tone with repeated experience and had significantly reduced arousal threshold levels during the treatment for the first, second, and third arousals.

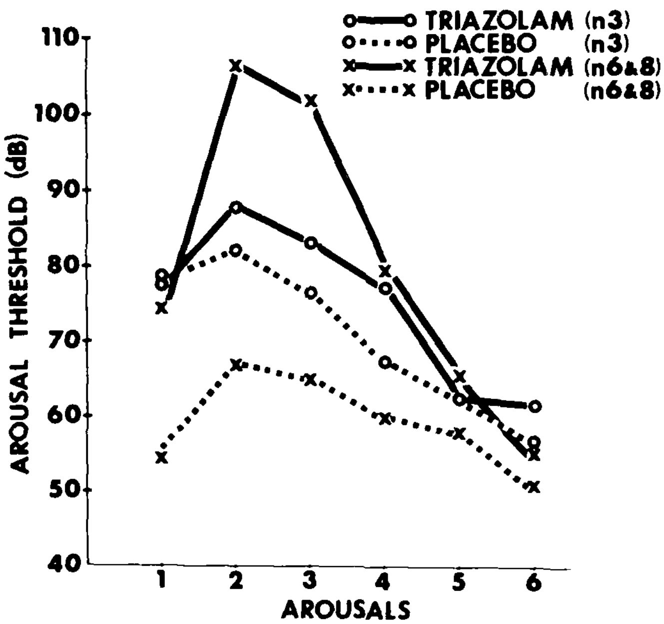

Fig. 2 - Mean arousal thresholds for the placebo-baseline night (n3) and for the mean of 2 treatment nights (n6 & 8).

In Fig. 3 are the arousal threshold curves for flurazepam and for triazolam. The curve for the combined placebo groups is also drawn for comparative purposes. The differences between the two hypnotic curves were not statistically significant for any arousal. The similarity of the two curves is most striking.

Latency of Return to Sleep.

Both hypnotics reduced the latency to return to sleep after arousal when compared to placebo (Fig. 4). The flurazepam

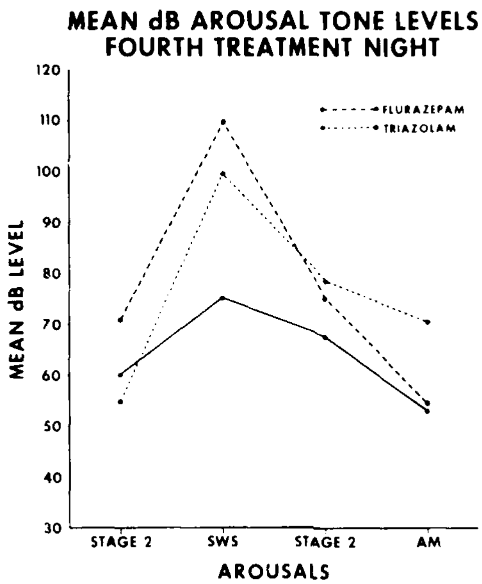

Fig. 3 - Comparison of arousal threshold for flurazepam and triazolam. Solid line is threshold for combined placebo groups.

group had a significantly shorter mean sleep latency following the first arousal period during treatment nights. During subsequent arousals, the sleep latencies for both flurazepam and placebo groups were short and did not differ significantly from each other. For triazolam subjects, latency of return to sleep following arousal during treatment was significantly reduced for the first, second, and third arousals.

CONCLUSIONS

These data show that these two benzodiazepines do increase arousal threshold. Bonnet, Webb & Barnard (1979) have reported a similar increase in arousal threshold after ingestion of flurazepam, 30 mg. Of particular interest is the

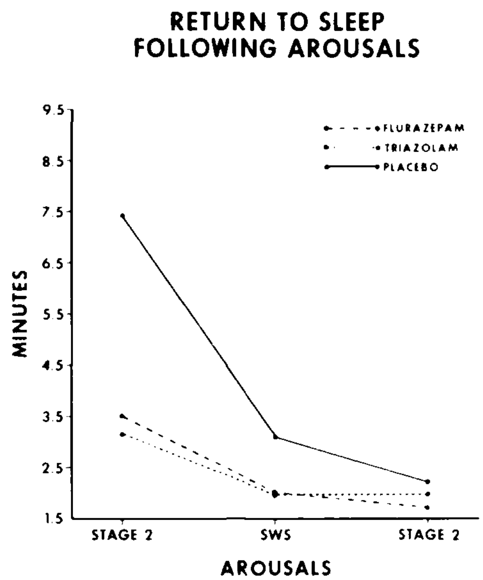

Fig. 4 - Latency of return to sleep (stage 2) following arousals.

similar time of night effect we found for flurazepam with its long acting metabolite N-desalkylflurazepam and for the short acting triazolam. A similar time of night effect was found for flurazepam and also for pentobarbital by Bonnet et al (1979). In our two studies as well as that of Bonnet et al, arousal threshold increased during the first two hours after administration, then decreased for the remainder of the night. The 0530 h arousal was very similar to that found 3-5 minutes after initial sleep onset and at these times the thresholds for placebo and drug groups were similar.

This time of night effect appears to be related to time post-administration and not due to stage of sleep. While our

highest arousal levels were found during SWS, Bonnet et al (1979) awakened their subjects only from stage 2 sleep, and they also found the highest arousal threshold near the second hour of sleep (see Fig. 5).

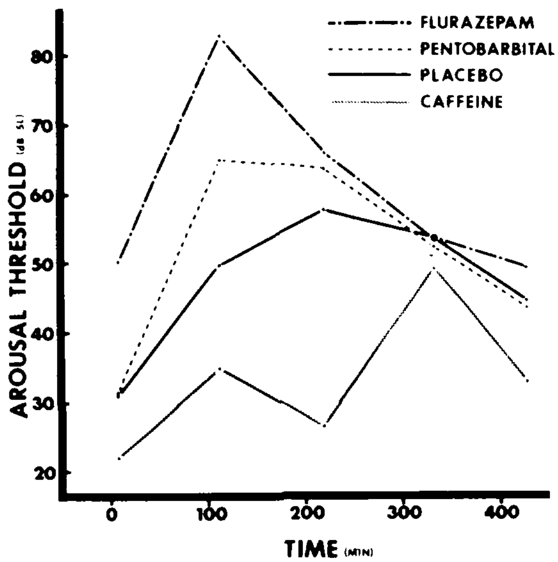

Fig. 5 - Time course of flurazepam, pentobarbital, placebo and caffeine as measured from auditory arousal threshold from stage 2 sleep. Adapted from Bonnet et al, 1979.

It is well established that with consecutive nights of use, there is a build up in plasma levels of N-desalkylfluraz-epam, but no build up of triazolam in plasma is seen. This contrasting pattern of accumulation in plasma was recently demonstrated over 37 nights of administration of triazolam and flurazepam (Johnson, Spinweber, Seidel & Dement, in press; Mittler, Seidel, Van den Hoed, Greenblatt & Dement, in press). It is generally assumed that with a build up of N-desalkyl-flurazepam levels there is more sedative effects. However,

recent studies have indicated the absence of a clear relationship between N-desalkylflurazepam plasma levels and daytime performance (Johnson & Chernik, 1982; Mendelson, Weingartner, Greenblatt, Garnett & Gillin, 1982). Johnson et al (in press) also found that triazolam and flurazepam produced a similar pattern of EEG changes during 37 treatment nights and five withdrawal nights. Both hypnotics showed an increase in sleep spindles and a decrease in delta activity.

What are the implications for those who complain of poor sleep because of noise? Most benzodiazepines will increase arousal threshold especially during the first hours of sleep and during this time period benzodiazepines are effective in assisting the return to sleep after being awakened. Our data suggest that these hypnotics would be less useful in maintaining sleep in noisy environments during the early morning hours. But once the sleep process is well established, it becomes more resistent to internal and external disruption of its nightly patterns. However, the results of the review by Johnson & Chernik (1982) indicate that it is unlikely that the hypnotically induced "deeper" sleep will lead to improved daytime performance.

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[illegible]

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INTRODUCTION

Previous studies have shown that both the amplitude and the habituation of various physiological responses to transient noise depend not only on the nature of the stimuli used but also on the type of objective and subjective measures which are used to assess the effects of noise (Firth, [illegible] ; Muzet et al., [illegible] ; [illegible], [illegible] ; Townsend et al., [illegible] ; [illegible] et al., [illegible]). The subjective evaluation of disturbed sleep varies greatly from one individual to another and subjective measures are sometimes very different from objective ones. In a study where subjects were exposed to traffic noises during [illegible] consecutive nights, we observed a clear dissociation between the criteria used to estimate habituation to noise (Muzet et al., [illegible] ; Muzet et al., [illegible]). There was a progressive disappearance of subjective complaints and of the global sleep stage organization changes due to noises in the first few nights, while distinct cardiovascular responses occurred and remained almost unchanged during the two week period of noise exposure. Many people who estimate their sleep as being noise disturbed tend to remedy this problem by the consumption of various sedative hypnotics. In light of this, we decided to study the possible modification of the electrophysiological and cardiovascular responses to noise during sleep, when under the influence of such a substance.

[illegible] young males, considering themselves as being "[illegible] sleepers" participated in this study. Subjects were in good health and had normal hearing. They spent [illegible] nights in the laboratory [illegible], all of which were consecutive with the exception of [illegible] which was [illegible] -ing night. These [illegible] subjects were randomly separated into three groups of [illegible] subjects each. Group A received a "placebo" during all nights, while groups B and C received respectively [illegible] triazolam on nights [illegible]. During all other nights, these subjects received the "placebo". The nature of the pill taken each night was unknown to both the subject and the experimentator. Airplanes noises recorded indoors with peak intensities ranging from [illegible] to [illegible] dB were semi-randomly presented throughout nights [illegible] at a rate of [illegible] noises per hour. Ambient temperature [illegible] and relative air humidity [illegible] were kept constant during the entire experiment. Standard electroencephalographic sleep recordings were made in addition to the following electrophysiological recordings: electrocardiogram, thoracic respiratory movements, body motility and rectal and skin temperatures. Sleep stage scoring was done according to the criteria of Rechtschaffen and Kales [illegible].

Electrophysiological responses to noise were separated into two categories:

[illegible] Sleep stage modifications, this category including [illegible] responses: no sleep stage change, sleep stage change, and [illegible] awakening;

[illegible] Presence or absence of other electrophysiological modifications such as, [illegible] activation phases, increases in muscle tone, [illegible] movements and respiratory rate changes.

The scoring of these electrophysiological responses was made for each airplane noise presented and only modifications occurring concomitant to the noise were considered. Similarly, cardiovascular modifications were scored concomitantly to each airplane noise diffused during the night. Heart beat intervals as well as beat by beat finger pulse amplitudes were recorded by an on-line computer system. The heart rate response (HRR) and the finger pulse response (FPR) were calculated for each individual noise. HRR amplitude was defined as the difference (in beats/min) between the acceleratory and the consecutive deceleratory values of the HRR. FPR amplitude was defined as the ratio between the smallest finger pulse amplitude of the FPR and the amplitude of the finger pulse observed before the onset of the vasoconstriction.

In this study we shall consider only the average HRR amplitude and the average FPR amplitude calculated for each subject and each night, over the entire night.

Statistical analysis included contingency tables (when comparing percentages) and dependent and independent Student's t-tests. Values of $p<$ [illegible] or better were considered as significant.

RESULTS

Electrophysiological responses to airplane noises

The effects of airplane noises on sleep stage changes are presented in figure 1. In group A ("placebo") there was no significant difference between the three noise-disturbed nights when considering the proportions of airplane noises inducing sleep stage change and EEG awakening. In this group, depending on the night, [illegible] to [illegible] of the noises were not accompanied by any sleep stage change, while [illegible] to 16% were associated with an EEG awakening. Therefore, there was no habituation to noise from N0 to N5 when considering the sleep stage modifications.

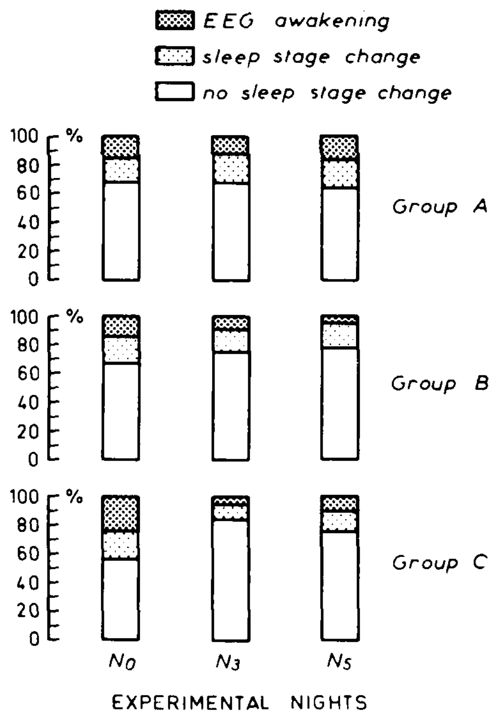

Fig.1 - Percentages of the different [illegible] sleep stage modifications associated with airplane noises in the three disturbed nights and within the three experimental groups.

In group B there was an increase in the percentage of airplane noises not associated with any sleep stage change in the two "drug" nights (N3 and N5) when compared to the "placebo" night (N0). Similarly, there was a decrease from N0 to N3 and N5 in the percentage of noise accompanied by EEG awakening. However, the differences tested by CHI² (contingency tables) did not reach the significant level (CHI² = 8.41 ; d.d.l. = 4).

In group C there was also an increase during the two "drug" nights in the percentage of airplane noises which were not associated with sleep stage change when compared to the "placebo" night. In addition, the percentage of airplane noises accompanied by an EEG awakening passed from 24% in N0 to 5% in N3, and 11% in N5. In this group the differences between the three nights were statistically significant at a level of $p < 0.001$ ($CHI^2 = 36.70$; d.d.l. = 4).

Noise provoked *EEG activation phases* increased significantly from N0 to N3 and N5 in the "placebo" group (see Table 1). In the two "drug" groups there was a decrease in the percentage of noises associated with EEG activation in N3 and N5 when compared to the "placebo" night (N0). However, the differences were not significant.

A similar observation was made when considering the percentage of airplane noises associated with an *increase in muscle tone* (see Table 1). In the "placebo" group the difference between the 3 disturbed nights was statistically significant, while the reduction of the percentages of noises associated with muscle tone modification did not reach a significant level in the two "drug" groups.

The *respiratory rate modifications* associated with airplane noises were distributed in a similar manner (see Table 1). In this instance, the significant level was obtained by group C in the comparison between the three disturbed nights, the reduction of the noise effects being greater in N3 than in N5.

Concerning the association between airplane noises and *appearance of body movements* there was no significant difference between the three nights in any of the 3 experimental groups (see Table 1).

Electrophysiological response	Experimental group	Experimental nights NO	N3	N5	CHI² d.d.l.=2	Significant level
EEG activation phase	A	38%	43%	51%	12.25	$p < 0.01$
	B	40%	31%	35%	2.88	n.S.
	C	37%	28%	33%	3.48	n.S.
Muscle tone increase	A	39%	57%	44%	12.36	$p < 0.01$
	B	42%	33%	32%	4.97	n.S.
	C	42%	30%	38%	5.43	n.S.
Respiratory rate change	A	43%	42%	50%	2.87	n.S.
	B	43%	32%	33%	5.87	n.S.
	C	46%	30%	35%	10.46	$p < 0.01$
Body movement	A	33%	30%	30%	0.28	n.S.
	B	24%	25%	20%	1.57	n.S.
	C	22%	19%	16%	2.11	n.S.

Table 1 - Percentages of airplane noises associated with electrophysiological responses.

Cardiovascular responses to airplane noises

Cardiovascular responses were separated into heart rate response (HRR) and finger pulse response (FPR), and averaged for each subject, over the entire night. The mean amplitude of HRR and FPR for each experimental group and for each experimental night are given in figure 2.

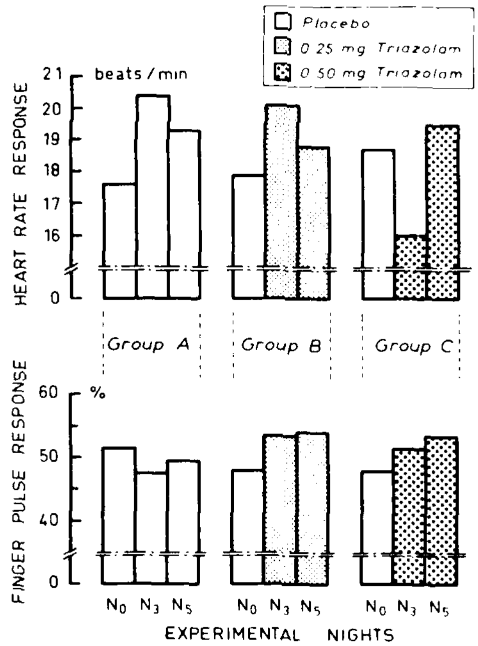

Fig.2 - Amplitudes of the average heart rate and finger pulse responses to airplane noises in the three disturbed nights and withing the three experimental groups.

Independent Student's t tests made for HRR and FPR showed no significant difference between the three groups for the "placebo" night (N_0). In group A and B there was no significant difference for HRR amplitude between the 3 experimental nights. In group C, dependent Student's t tests showed a significant difference of HRR amplitude between N_0 and N_3 ($t = 2.547$; d.d.l. = 6 ; $p < 0.05$) and between N_3 and N_5 ($t = 3.815$; d.d.l. = 7 ; $p < 0.01$).

Dependent Student's t tests showed no significant difference for the FPR when comparing the three nights in group A and B. In group C, the only significant difference in FPR amplitude was found between N0 and N3 ($t = -2.910$; d.d.l. = 5 ; $p < 0.05$).

DISCUSSION

Our results pertaining to the "placebo" group confirm earlier observations (Globus et al., 1973 ; Johnson et al., 1973 ; Griefahn, 1975 ; Townsend et al., 1976 ; Muzet et al., 1981), which showed that there is no habituation of noise-related electrophysiological and cardiovascular modifications, over a period lasting several nights. In our "placebo" group, the percentage of noise induced EEG activation phases and muscle tone increases was infact, significantly higher during the second and third noise disturbed nights when they were compared to the first one.

The ingestion of triazolam decreased the number of noise-provoked sleep stage changes and EEG confirmed awakenings when comparing "drug" to "non drug" nights, and the differences were highly significant for the 0.50 mg dose. This effect of triazolam on EEG sleep stage modifications can be related to results obtained by Ehrenstein et al. (1980) on EEG responses and by Bonnet et al. (1979), and Johnson et al. (this volume), who reported an increase in auditory arousal threshold after ingestion of benzodiazepine hypnotics.

In addition, other noise-associated electrophysiological changes were less frequent during "drug" nights than during "placebo" nights, although the difference was only statistically significant for the noise-provoked respiratory rate changes.

Results concerning cardiovascular responses to airplane noises were slightly different. The heart rate response was significantly reduced, only during N3 in the group receiving 0.50 mg of triazolam. This reduction was not present during N5, and for this night the HRR was actually greater than in N0. The finger pulse response was also

significantly modified during N3 when compared to N0 in the 0.50 mg dose group.

Although there were significant differences in cardiovascular responses to noise under the influence of triazolam, these variations were moderate. Therefore, the effects of the benzodiazepine hypnotic were not as pronounced in cardiovascular responses as they were in EEG and other electrophysiological measures.

CONCLUSIONS

This study has shown that a benzodiazepine hypnotic can reduce the number of electrophysiological responses and to a smaller degree the amplitude of cardiovascular responses to noise. The effects of the drug can be dose dependent, however, they are sometimes limited to the first night of drug ingestion.

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EFFECT OF INTERMITTENT AND CONTINUOUS TRAFFIC NOISE ON VARIOUS SLEEP CHARACTERISTICS AND THEIR ADAPTATION.

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I. INTRODUCTION

Five years ago, in her introductory survey of the work on the effect of noise on sleep, Griefahn[1] repeatedly mentioned the difficulty of drawing conclusions from the results of the numerous experiments that could not easily be compared. Except for an increase in the number of experiments, this situation has not changed greatly. This is not surprising when we consider the number of permutations and combinations inherent in defining experiments with various noise characteristics, introduced with various temporal patterns, at different parts of the sleep cycle, at different parts of the night, with greatly varying subjects of various ages and temperament, and looking for various possible primary or secondary responses, and finally looking for possible effects on health due to these responses. This last problem is made still more complex by our lack of knowledge of why we must sleep.

We can only hope that, as we increase the number of comparable experiments and achieve greater agreement among experimenters, some patterns will emerge to increase our confidence in our conclusions regarding some of the effects of some noises on some sleep parameters. If

we're lucky we might even be able to relate these to health, at least for some people.

II. METHOD

The response of Ss was measured by EEG using frontal electrodes[b]. The signals were recorded on paper, for detailed observation where necessary, and also on magnetic tape. The latter was played back at 70 times the recording speed which made the signals clearly audible and also permitted the use of standard audio equipment for frequency analysis. The main frequencies selected by 1/3-octave filters were the alpha, delta and beta frequencies. The experiments dealing with effect of noise on deep sleep defined the last term as that part of sleep in which spindles occurred. These were clearly audible as "chirps" when the tape was played back at high speed.

The individual truck noises were recorded at 15 m from the line of travel of trucks whose speed was about 90 km per hour. Continuous traffic noise was recorded 15 m from the curb of a road carrying 3000 vehicles per hour.

III. INTERMITTENT SINGLE TRAFFIC EVENTS

Because of the intensity of aircraft noise and sonic booms, their effect on sleep formed a large part of the earlier studies. Truck noise also received considerable attention. Figure 1 contains mostly old familiar data,[2] showing the probability of response as a function of the

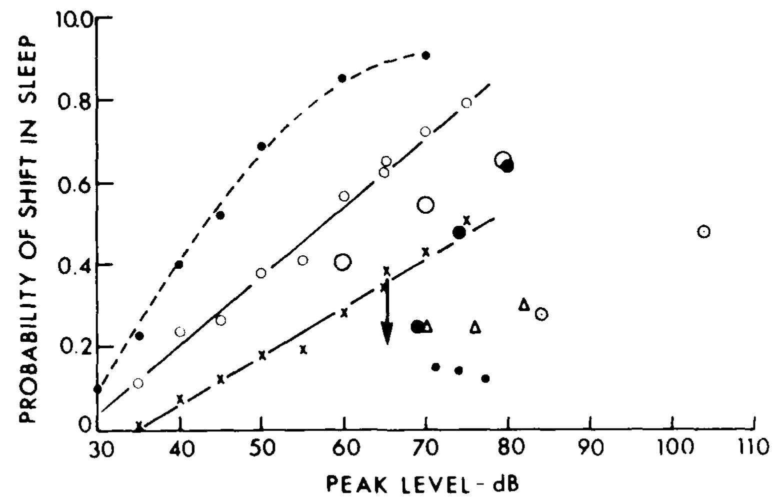

Fig. 1 - Response of sleeping subjects to various intermittant noise events of various durations.

intensity of the noise stimulus, for a variety of kinds of noise and duration. (The source of the data is given in reference 2).

The top dashed curve involved a waking response resulting from a highly impulsive noise source which was maintained at a constant level for about 200 seconds, then raised 5 to 10 dB for additional periods until the subject awakened.

The line drawn through the crosses gives the probability of waking due to the passage of a truck, with a total duration of noise of 29 sec. per passage. There were seven passes per night. At the 65 dB level there are two crosses on this line. The top one shows the value from more recent work[5] when 20 truck passes per night were used. The response is effectively unchanged. However after two weeks the number of wakings dropped to half value as shown by the arrow pointing downward.

The large solid circles at about 70, 75 and 80 dB give the probability of waking due to aircraft passes with the noise duration being about 5 seconds.

The small solid circles and triangles, in the same general region of the graph, show the probability of waking from sonic booms whose duration is about 0.3 seconds. The two open circles farther to the right involve the same duration of noise but using low frequency tone bursts and measuring the probability of shift in sleep level.

The probability of shift in sleep level with truck noise of 30 second duration is shown by the solid line drawn through the open circles. Here again we have two values at the 65 dB level. The upper one is again from more recent work[5] using 20 truck passes per night.

Ohrström and Rylander[3] have recently published data on body movements during sleep, caused by truck noises of [illegible] second duration. These

results are shown by the large open circles just below the last mentioned line. Since not every body movement will result in waking they properly lie above the crosses and are consistent with the rest of the data.

It is obvious from this figure that the duration of the noise stimulus plays an important part in determining the response, whether waking, sleep level changes or body movements. Lukas[4] published a survey of data in 1975 which took account of the duration of the stimuli by converting them to EPNdB. He achieved a considerable reduction of the scatter of the data from various sources. Can this be extrapolated to continuous noise such as that from dense traffic? Apparently this is not the case.

Not shown on this composite graph are the effects of truck noise on the percentage of deep sleep[5]. Eight to twenty truck passes at peak levels of 65 dB caused a decrease of 3% in the amount of deep sleep of 17 subjects.

IV. CONTINUOUS, FREE-FLOWING, TRAFFIC NOISE

1. Number of Wakings.

Table 1 is taken from a recently published report[6] in which continuous traffic noise was presented to subjects every other night for 12 nights while the nights in between were quiet. When the level of traffic noise is 47 dB the number of wakings is about 13 per cent higher than on the quiet nights. Table 2 shows the results when the traffic noise is 60 dB which resulted in a 36 percent increase in wakings. These results are plotted in Fig. 2.

In the same figure are plotted the results of Ohrström and Rylander[7] on wakings and body movements. However, their number of wakings were not measured but rather estimated by the subjects and so their meaning is probably more qualitative than quantitative. We can only say therefore

Table 1. Average per cent deep sleep for nights with traffic noise at a level of 47 dB compared with nights without noise (background level 32 dB) for 14 subjects. Also shown are the total number of wakings in 12 nights.

Subject	% "Deep" Sleep in noise	no noise	Diff.	No. of Wakings in noise	no noise	Diff.
1	69.4	67.7	+ 1.7	23	22	+ 1
2	61.0	62.4	- 1.4	17	15	+ 2
3	71.4	67.8	+ 3.6	14	14	0
4	67.1	61.7	+ 5.4	13	13	0
5	64.9	63.5	+ 1.4	3	2	+ 1
6	60.6	59.6	+ 1.0	17	9	+ 8
7	64.6	62.1	+ 2.5	12	8	+ 4
8	68.5	67.6	+ 0.9	23	23	Ø
9	57.2	60.1	- 2.9	5	0	+ 5
10	68.2	66.6	+ 1.6	28	19	+ 9
11	65.9	66.9	- 1.0	14	11	+ 3
12	66.3	63.9	+ 2.4	17	11	+ 6
13	69.3	63.7	+ 5.6	39	46	- 7
14	56.8	57.0	- 0.2	14	19	- 5
Average	65.1	63.6	+ 1.5	17.1	15.2	+ 1.9
% Change			+ 2.4			+12.6

Table 2. Average per cent deep sleep for nights with traffic noise at a level of 60 dB compared with nights without noise for 12 subjects. Also shown are the total number of wakings for 12 nights.

Subject	"Deep" Sleep in noise	no noise	Diff.	No. of Wakings in noise	no noise	Diff.
1	72.4	69.2	+ 3.2	25	17	+ 8
2	66.0	64.4	+ 1.6	29	24	+ 5
3	69.4	64.6	+ 4.8	16	15	+ 1
4	69.0	66.0	+ 3.0	23	15	+ 8
5	68.3	66.9	+ 1.4	71	43	+28
6	66.0	63.0	+ 3.0	54	44	+10
7	76.7	72.7	+ 4.0	18	10	+ 8
8	71.6	65.9	+ 5.7	8	4	+ 4
9	66.0	64.4	+ 1.6	26	28	- 2
10	71.6	67.1	+ 4.5	19	24	- 5
11	73.4	71.6	+ 1.8	21	22	- 1
12	72.3	67.9	+ 4.4	57	35	+22
Average	70.2	67.0	+ 3.25	30.6	23.4	+ 8.5
% Change			+ 4.8			+36.3

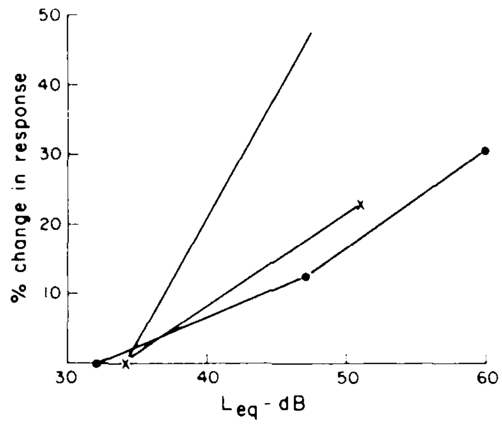

Fig. 2 - Effect of continuous traffic noise on the percentage change in wakings (points, from tables 1 and 2, line from ref. 3) and body movements (crosses, from ref. 3)

that we are in agreement that continuous traffic noise tends to increase the number of wakings.

The increase in number of body movements agrees more closely with our data on number of wakings.

2. Percentage change in deep sleep.

The percent "deep" sleep is readily measured, by timing the "chirps" with a stopwatch. The data are shown in Tables 1 and 2 and plotted in Figure 3. The percent deep sleep increases with an increase in traffic noise (noise from 3000 vehicles per hour measured at 15 m from the curb). This may appear inconsistent with the fact that there is more waking and more body movement. It suggests that continuous traffic noise improves ones sleep. Yet most other measures contradict this[3].

That contradiction can be eliminated if the change in deep sleep is not a primary effect . There are many reports that indicate that

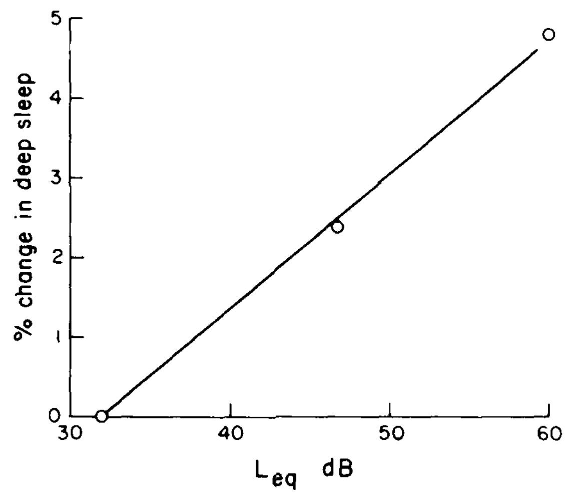

Fig. 3 - Effect of continuous traffic noise on percentage change in deep sleep (data from Tables 1 and 2).

deprivation of REM sleep results in an increase in stage 4 sleep. Since our simplified definition of deep sleep combined stage one, dreaming and waking all into one group it could have happened that the noise caused a decrease in dreaming as a primary effect. The increase in "deep" sleep then showed up as a secondary effect and hence as a possible sign of a deleterious effect of the noise.

This, of course, remains speculations.

It is interesting to compare the above results with those using intermittent truck noise[5]. In that case the deep sleep was reduced by three percent.

V. LATENCY OF SLEEP ONSET

Our subjects, like most working people, ended their sleep by an alarm clock. In that case an increase in latency of sleep onset due to noise may reduce the total amount of sleep even if the percentage of deep sleep

is not reduced. This latency was therefore measured by timing the interval from lights-out to the onset of spindles which indicated the beginning of deep sleep[6].

Neither the 47 dB level nor the 60 dB level of traffic noise showed any measurable effect on the average latency of the 14 and 12 subjects respectively. Individual differences, however, were large. Figure 4 shows the results for one subject (S.E.L.). Although there is a great laboratory-effect as indicated by the steady drop to the 24th night, the difference between that with 60 dB of noise and without noise seems to remain. The average latency for the quiet nights was 11 minutes while that for noisy nights was 18 minutes

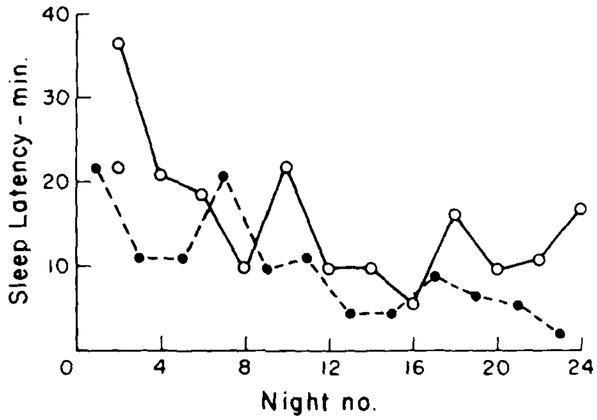

Fig. 4 - Sleep latency for one subject as a function of number of nights exposure to continuous traffic noise at a level of 60 dB (circles) compared to that for quiet nights (solid points).

Since the average effect of the noise was near zero, all the data for both groups can be combined to provide a laboratory adaptation curve. Figure 5 shows the result (with the values for each pair of nights averaged to reduce the number of points to 12). Adaptation seems to be complete in about 10 days.

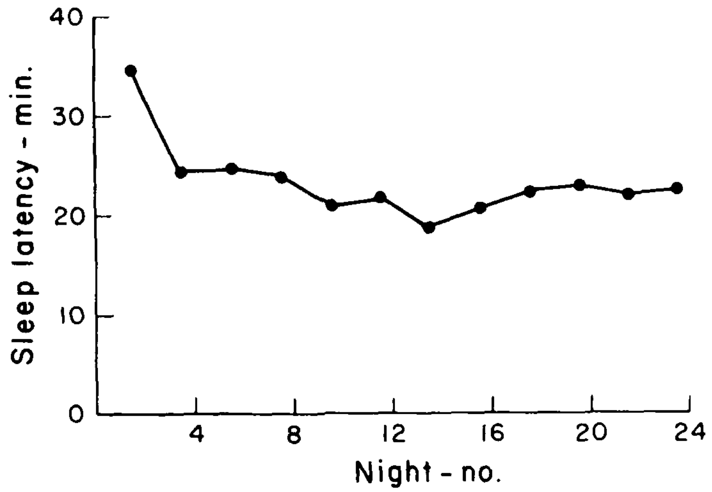

Fig. 5 - Average latency of sleep onset for 26 Ss as a function of nights in the laboratory.

VII. NOISE AND THE SLEEP CYCLE

Herbert and Wilkinson[7] suggested 10 years ago that there was a correlation between performance and disturbance, on the night before, of the cyclical nature of sleep (which they referred to as "rhythmicity"). Accordingly an attempt was made to measure the effect of continuous traffic noise on this sleep characteristic. In individual cases the effect may be dramatic (see Fig. 13, reference 2). But in general this is not as easily determined and the results to date are not conclusive. Our problem lies in the definition of a cycle. The square wave character of a record of the amplitude of the α-frequency from frontal electrodes (reference 2, Fig. 1) seems to make this an easy task. But few subjects show so persistent an adherence to a uniform pattern even after being wakened and pushing a button. If waking represents the end of a cycle, regardless of how promptly this is followed by return to deep sleep, then clearly the duration of the cycle, as well as its uniformity, is

disturbed, since the number of wakings has been increased by continuous traffic noise as shown in Fig. 2.

Table 3. The effect of various noise stimuli on various sleep parameters.

Stimulus / Sleep Parameters	60 dB Level < 1 sec	10 sec	200 sec	continuous traffic	Adaptation
Prob. level shift	0	0.5		?	0
Prob. Waking	0.1	0.25	0.8 ?	0.3	2 wks
Latency				(+,-)	yes
% deep sleep		- 3		+ 4.8	?
% dreaming				(-,?)	
Sleep duration				(+,-)	
Sleep cycle disruption		yes		yes?	some
Quality		-		(+,-)	no ?
Lab effect	yes	yes		yes	yes

CONCLUSION

Table 3 shows, in a crude way, what effect some kinds of noise have on some sleep parameters and if adaptation occurs. The entries are by no means uncontroversial nor comprehensive, but are meant to emphasize the complexity of the problem and how much is unknown. The relation to health is omitted entirely for obvious reasons.

We can say with reasonable confidence that there is consistent waking and shifting of sleep level for intermittent noises of various kinds. The

effects increase with intensity and with the duration of the noise up to a limit. The waking reaction is reduced to about half value in two weeks[8]. For continuous traffic noise there is only a small increase in waking and, unexpectedly, also an increase in the percentage of the night spent in deep sleep. The average latency of sleep onset is not affected by traffic noise but individuals differ greatly. The effect on the cyclical nature of sleep is uncertain since it depends on how a cycle is defined.

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PROPOSALS FOR FURTHER RESEARCH ON NOISE-INDUCED SLEEP DISTURBANCES

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Regarding the conclusions and recommendations of the last Congress held in Freiburg 1978 a considerable body of work has been done within the last few years. The progress since then is centered on 5 main topics:

1. Parameters presumed to be sensitive to noise and noise-induced sleep disturbances:

- Physiological parameters. In the past, sleep was described mainly by the total sleep time, the number and duration of awakenings, and of the single sleep stages. It became then increasingly common to describe sleep also qualitatively by its rhythmicity and by the distribution of sleep stages and awakenings. In addition several vegetative reactions (cardiovascular and respiratory) were recorded and proved to be largely resistant to adaptation.
- Subjective assessment. Scales were developed for assessing sleep quality, the actual situation (fatigue, alertness etc.) and mood.
- Performance. Several performance tests were applied and partly proven to be related to noise and/or noise-induced sleep disturbances.

2. Interaction with moderator variables. Variables assumed to interact with noise and sleep were recorded more and more. The

relation between noise annoyance and sleep quality of residents living in noisy areas is influenced by age, health, noise susceptibility etc..

Noise-induced reactions of EEG-data, subjective assessment, and performance are more or less dependent on sex, age, years of exposure, and experimental conditions.

3. Habituation. Habituation to long-term exposure was studied using 2 main approaches:

- follow-up studies
- cross-sectional studies including an experimental condition were prefered. During the experimental condition noise level was either raised or reduced. Habituation was found to be small or not existent.

4. Techniques of recording and evaluation. Methods which can be applied in field studies should be vastly resistant against artifacts, easy to record, and easy to evaluate. Especially in the analysis of the EEG and EOG automatic systems were applied and improved.

5. Cooperation. Cooperation between different laboratories were initiated. The best example is the joint European project designed to investigate the effects of noise on sleep and subsequent performance. 4 teams from Britain, France, from the Netherlands and the Federal Republic of Germany were involved in this investigation. Methods of recording and evaluation were comparable enabling to pool the results of about 1000 nights of 70 subjects.

However, a considerable list of problems still remains to be solved in the future. The disadvantage of sleep research is that only one experiment can be executed within 24 hours and thus answers cannot be given at short sight. The extremely time-consuming research is a demand for more directed work and for concentration to only a few goals.

The most important question still unanswered is whether noise causes permanent health effects in the long run. Pooling the results for the joint European project it could be pointed out that people with long-term-exposure to traffic noise still sleep better in relative quiet nights. This was demonstrated for physiological data, for subjective assessment, and for performance the next day, suggesting that there is no complete adaptation even after years of noise exposure.

The 3 indicators (or better the presumed indicators) of sleep quality are often not related to each other. This means that the postulated pathway for the development of health disorders (noise - sleep disturbances - subjective assessment - impaired performance) is not obligatory.

One very important goal for future research then is to determine valid indicators of sleep disturbances with respect to health and well-being. There is still a need for physiological parameters and practicable techniques for recording and evaluation, which can be easily applied in the field. This basic research as well as the determination of the validity of EEG reactions and vegetative alterations has to be executed in the laboratory. After-effects as there are subjective assessment and performance the next day should be recorded not only in the morning but several times a day.

The results of field experiments are, as a rule, smaller and often less clear than in the laboratory. The reasons are probably on the one hand the number of variables which cannot be controlled sufficiently in the field and on the other hand the experimental design. In most of the studies carried out the subjects slept under both noisy and quiet conditions. But because of the transient character of the experimental condition (raised or reduced sound level) the situation per se does not change substantially and this presumably keeps the effects relatively small. It is therefore necessary to record the

effects of lasting counter measures. These measures should be practicable and generally applicable for the prevention of negative noise effects to residents living in noisy areas. The reduction of noise levels can be attained by

- decreasing the sound conduction by fitting double glazing or sound barriers (The single study demonstrating that - transient - sound insulation by double glazing is inefficient for cardiovascular responses to noise peaks should be replicated).
- reducing noise pollution at its source by slowing down the traffic speed, closing streets totally or selectively for trucks and/or motorcycles.

It is furtheron of practical interest to know the hours of particular sensitivity. Road traffic then can be reduced or prohibited for the appropriate time.

In the last years some papers demonstrated that continuous noise is less disturbing than intermittent noise. But with regard to noise-induced sleep disturbances we have no definition for continuous and intermittent noise. Research on this problem covers the question of the prediction of noise-induced sleep disturbances by acoustical data. An important question is whether the equivalent noise level is a useful predictor for noise effects and preventive measures or whether we better should refer to the number or the peak levels, the noise intervals, etc..

Critical groups with a particular sensitivity to nightly occurring noise, their psychological determinants and physiological characteristics have to be defined.

The international cooperation already initiated and successfully executed has to be enforced. Cooperation requires a minimum consensus with regard to the methods applied. The advantage then is a greater reliability of the combined results.

As it was suggested by Team 6 working on community responses to noise a collaboration with this group and with Team 4 working on performance is desirable and will be helpful for the solution of many problems.

Poster Session

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DAYTIME NOISE STRESS AND SUBSEQUENT NIGHT SLEEP: INTERFERENCE WITH SLEEP PATTERNS, ENDOCRINE FUNCTIONS AND SEROTONERGIC SYSTEM.

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INTRODUCTION

Strong noise has various extraauditory effects on physiological and psychological processes in man (for literature see Borg, 19[illegible]; Fruhstorfer and Hensel, 1978). Among these effects sleep disturbances caused by noise during sleep have been studied in detail (for literature see Griefahn, 1980). Only little attention, however, has been paid to the problem, whether longlasting daytime noise might have after-effects on sleep processes during subsequent undisturbed nights. Indications for such an influence came first from Blois et al. ([illegible]) who found after noisy days a significantly reduced total sleep time at the cost of REM sleep. Later Fruhstorfer et al. (19[illegible]) found increased slow wave sleep at the [illegible] of sleep stage 2 after daytime noise exposure. The aim of this study was to extend the knowledge about these extraauditory noise effects by investigating simultaneously sleep patterns, endocrine [illegible] sleep and the serotonergic system which plays a role in the maintenance of sleep.

MATERIAL AND METHODS

Six healthy non-obese paid male volunteers [illegible] years [illegible] 7 consecutive nights in the laboratory: [illegible] nights for [illegible]

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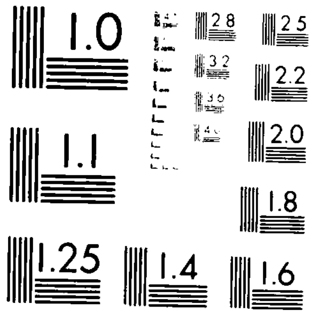

MICROCOPY RESOLUTION TEST CHART

after staying 8 hours per day in an experimental room, where they were exposed for two days to 83 dB(A) pink noise, and finally one baseline night. Throughout all nights EEG, EOG, EMG, ECG and respiration were continuously recorded. Before the second night, a catheter was inserted from an antecubital vein into the axillary or subclavian vein where it remained for the following five nights. During these nights, blood samples were taken without disturbance of the sleeper: every 30 min for the determination of adrenocorticotropic hormone (ACTH), human growth hormone (HGH) and prolactin (PRL) and every 60 min for the determination of tryptophan (TRY), serotonin (5-HT) and 5-hydroxiindolacetic acid (5-HIAA) levels. ACTH, HGH and PRL were determined with routine clinical radioimmunoassay methods, whereas TRY, 5-HT and 5-HIAA determination was performed with HPLC analysis. The sleep data were scored automatically by cluster analysis and classified into the usual sleep stages. For statistical analysis either Wilcoxon signed rank test or multivariate variance analysis were used.

RESULTS

The EEG sleep data showed no significant change in the percentage of the different sleep stages after daytime noise. Slow wave sleep (stage 3 and 4) was uneffected, but splitting it revealed in 4 subjects an increase in stage 4 sleep with a simultaneous decrease in stage 3 sleep. The stability of the sleep stages was altered: all subjects showed a decrease in stability of sleep stages 2 and 3 ($p \leq .05$), while 5 subjects showed a corresponding increase in stability of stage 4 sleep. REM sleep always remained uneffected. Concerning the endocrine functions, the usual increase of ACTH in the morning was uneffected in all subjects, while 3 subjects showed an increase in HGH peak and PRL plateau during the nights after daytime noise. In the other 3 subjects these parameters showed no difference between the nights. As for the levels of TRY, 5-HT and 5-HIAA, all were generally lowered during the nights after daytime noise ($p \leq .07$), but showed no consistent change in the trend during the nights (Fig.1).

DISCUSSION

Contrary to the results of our previous study (Fruhstorfer et al. 1983) we found in this experimental series no significant increase in slow

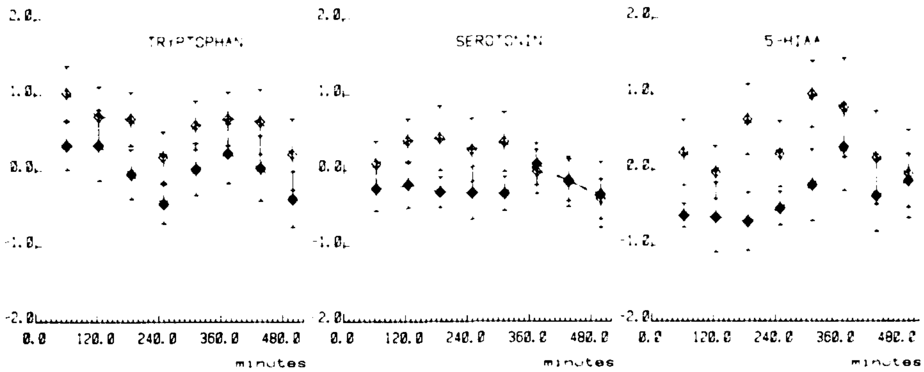

Fig.1 - Comparison of TRY, 5-HT and 5-HIAA values from nights following days without noise (open squares) with the values from nights following daytime noise (closed squares). Means and standard errors from all subjects; the data were normalized by Z-transformation.

wave sleep. There was, however, an increased stability of sleep stage 4 and a decreased stability of the stages 3 and 2. Additionally at least in 3 subjects the values of HGH and PRL showed a tendency to a higher level during the nights after daytime noise exposure, what might be interpreted as a sign of increased metabolic demands. Therefore at least the conclusions from both experimental series might be similar, pointing less towards a constant high arousal level after daytime noise which would restrain the central nervous system from recovery, but rather towards an increased demand for restorative processes. When including the peripheral serotonergic system in such a concept it has to be considered that only very little is known in humans about the correlation between plasma and brain concentrations of TRY, 5-HT and 5-HIAA. Experiments in cats show that central serotonergic neurones are most active during day, especially during arousal, and less active during sleep (for literature see Jouvet, 1983). Experiments with rats admit the assumption that a low rate of 5-HT release is correlated with a high rate of 5-HT synthesis (Héry et al.

1972). On the basis of these data it can be speculated that noise stress during the day activates central serotonergic neurons. During the night this activation might be followed by a higher rate of transmitter synthesis and lower plasma levels.

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ENVIRONMENTAL RESEARCH PROGRAM: EFFECTS OF NOISE ON HUMAN BEINGS

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INTRODUCTION

For an effective protection against noise emission and immission limits often have to be established. These limits are to make sure that harmful environmental influences are avoided. The Environmental Research Program concerning effects of noise on human beings has the main aim to find out the conditions under which harmful influences, i.e. health hazards, considerable disadvantages, and considerable annoyances,can occur. Since the last congress in Freiburg 1978 a variety of projects has been funded. According to the recommendations of the project group "Combating Noise Pollution" /1/ formed by the Minister of the Interior in 1977 the projects were mainly concerned with

- actual noise configurations (every-day noise)
- over a long period of time (long-term effects)
- in real-life environmental situations (field studies)
- with consideration given to other environmental factors (combination of irritants).

RESEARCH ACTIVITIES

The main topics of the research activities have been

- cardiovascular effects of noise /2/ /3/

- noise-induced sleep disturbance /4/ /5/
- synergetic effects of environmental and working noise /6/
- social surveys about the community reactions to traffic, aircraft and shooting noise /7/ /8/ /9/ /1o/
- effects of noise on performance and information processing /12/ /13/ /14/ /15/.

The research activities have extended our knowledge about the effects of noise considerably.
Of special importance are the results of studies showing that environmental noise may be a risk factor for cardiovascular diseases and defining possible risk groups.
The social surveys about the community reactions to transportation noise give a comprehensive description of the kinds and the degrees of nuisances caused by noise in existing environmental situations. Current surveys dealing with the reactions to vibrations in residential areas and to noise in recreation areas will extend our knowledge further. Though numerous questions have to be cleared up a lot of qualitative and quantitative information about the consequences of special noise limits is available now.
The research results about the effects of noise on performance show an extraordinarily complex picture of the mechanisms which lead to disturbances. Thus, general statements about the relation between noise level and disturbance being valid for many situations and for larger groups of individuals seem to be impossible. In individual cases, however, specifications about the disturbing effect of noise levels can be made /16/.
The studies about noise-induced sleep disturbances have yielded a variety of new information but despite considerable research efforts important questions already being asked at the last congress in Freiburg /17/ cannot be answered yet:

1. What is the nature and function of sleep, how can its significant characteristics be measured?
2. What are the health and performance implications of noise disturbed sleep?

Because of the important consequences for public health car-

vascular effects of noise and noise-induced sleep disturbances are topics of the current and future research activities, too. But as epidemiological studies can only point out statistical relations between noise parameters and health hazards but not causal ones longitudinal studies have to be performed in which well defined risk groups will be surveyed medically over a long period /18/.

Also with social surveys there is more need for longitudinal studies than for further cross-sectional studies nowadays. Our knowledge about sensitization or adaptation, the community response to new constructed traffic routes, the subjective effectiveness of noise protection measures is too poor yet and it can especially be improved by longitudinal studies. This knowledge is urgently needed to confirm the necessity and the benefits of further noise control measures and to find out the most effective way for noise abatement.

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COMPARISON OF THE IMPACT OF RAILWAY NOISE AND ROAD TRAFFIC ON SLEEP

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INTRODUCTION

Sleep disturbance by train and road noises was studied through *in situ* physiological recordings on two groups of people submitted to both types of exposure for comparing the respective habituation of sleep with respect to the type of disturbing noise and with respect to acoustic characteristics of each situation.

METHOD

Two sites were selected : the French provincial town of Macon and a village called Domarin. The acoustical characteristics are indicated in Table 1. At both sites people were exposed at the same time to both kinds of traffic and peak noise levels of trains were of the same order of magnitude.

Ten subjects were selected at each site (a total of nine men and 11 women, average age 35 years, for the two sites).

The physiological reactions of sleeping subjects were recorded with the use of a telemetry transmitter. The magnetic tape and graphical recording instruments were housed in a recording van. A microphone for the measurement of the noise level in the bedroom was connected to a logarithmic sound meter and tape recorder. Outdoor noise was studied by means of a statistical analyzing instrument. The following physiological recordings were made for each subject : EEG (vertex occipital), EOG (eye movement), EMG (chin muscle) and ECG (cardiac activity through precordial electrodes).

The recordings were evaluated in accordance with the procedure given by Rechtschaffen and Kales. The immediate response to each vehicle transit noise were grouped into five categories : nil reaction ; weak transitory response ; change in sleep level ; awakenings ; and total reactions (that is, combinations of all kinds of reactions).

All noises rising above the background level in bedroom were identified in the following terms : peak level ; duration above background noise ; emergence (that is, difference between peak level and background noise) ; type of noise (train and road).

Characteristics of the sites

Characteristics of the sites

	Train noise		Road noise			Background noise level (dB(A))	L_{eq} total (dB(A))
	L_{eq} night (dB(A))	Traffic (vehicles)	L_{eq} night	Traffic (vehicles)	% Truck		
Macon	69	80	69	500	60	45-50	72
Domarin	50	15	52-53	300	60	30	55

RESULTS

Disturbance to sleep with respect to L_{eq} values and type of traffic

Site	L_{eq} (dB(A))	Trains: Number of occurrences of noise	Trains: Number of responses	Trains: Per cent positive responses	Trains: Confidence interval $p = 0.05$	Road vehicles: Number of occurrences of noise	Road vehicles: Number of responses	Road vehicles: Per cent positive responses	Road vehicles: Confidence interval $p = 0.05$
Mâcon	69	617	114	18.5	15–22	2274	340	15.0	13–17
Domarin	52	114	17	14.9	3–38				

Correlation between the peak noise level and the "zero response"

Type of traffic	Site	Linear regression equation	r	Significance level
Rail	Mâcon	$y = 0.82x + 126$	0.89	$p < 0.01$
	Domarin	$y = -0.50x + 119$	-0.69	$p < 0.01$
Road	Mâcon	$y = 0.59x + 117$	0.89	$p < 0.01$

CONCLUSION

For the same value of L_{eq} there were three times as many disturbances to sleep due to the noise from road traffic as there were due to the noise from trains. However this was not because people become more accustomed to train noise but rather because such disturbances are closely

related to the number of noise occurences and, in the case of our site, for the same value of L_{eq} there were three times as many road vehicles as trains concerned.

For the same type of traffic (rail traffic) the number of disturbances to sleep falls appreciably as the value of L_{eq} decreases.

In sites with very different acoustical situations the most important factor of disturbance is peak level for a single event and L_{eq} for a general index, but in a noisy place the factor that makes the most difference to instantaneous sleep reactions is duration while in a quite place it is emergence.

One does not observe specific effects of train or road noise on the threshold of immediate sleep disturbance.

As to modalities of sleep disturbance, (1) when emergence becomes higher, awakenings increase, and when duration becomes longer, sleep level changes increase, and (2) at the noisier site, 78 events out of 100 do not interfere, and in the most favorable case (duration shorter than 20 s) 86 % events do not interfere, while at the quieter site, 97 events out of 100 do not interfere with sleep, and in the most unfavorable case (peak level higher than 54 dB, and emergence higher than 12 dB), one still observes 90 % of nil reaction. These results are in contradiction with the ordinary notion of saturation of reactions when the number of stimulus increases, because one observes here better adaptation in the quieter place than in the noisier one.

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REVIEW OF COMMUNITY RESPONSE TO NOISE

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INTRODUCTION

Almost 20 years ago the Final Report of the Committee on the Problem of Noise was presented to the British Parliament and, in representing the results of some years of very thorough and basic work on the topic of community response to noise, laid out a prospectus of the *problems which, then and now, needed to be solved:*

These problems *remain with* us, and it is clear that in the last 20 years substantial progress has only really been made in the first three of these categories.

1. Noise from motor vehicles
2. Noise from other surface transport (Including noise from railways, boats and hovercraft)
3. Aircraft noise (military and civil, including sonic booms but not general aviation or helicopters)
4. Noise from industry
5. Noise from construction and demolition
6. Entertainment and advertising noise
7. Noise in the country

We need periodically to review progress over fairly long periods, and also to remind ourselves of the basic underlying philosophy of our research. By now this whole field has become a little less abstract than it was and is already perhaps in danger of excessive reification: we do not ask ourselves, for example, what community response _is_. It clearly is not, if we look at the literature, _any_ response which may be observed in the community: we cannot see, for instance, any sign that there are individuals and groups who see positive value in some noises. Community response has been implicitly defined as unfavourable, even to the extent that laboratory studies (which by definition provide no normal social context for the noise evaluated) often fail to differentiate between loudness and noisiness.

It may well be the case that the term 'community response' has reached the end of its useful life. In the earliest days of social investigations of noise it was essential, as a guide to research and policy, to estimate the percentage of the population exposed to each source of noise nuisance. This is now a less frequent requirement (although still useful as part of the environmental monitoring process, see, for example, Fidell, 1978). More typically found are those studies in which the responses of large numbers of individuals are correlated with individual or representative noise measurements. These studies do not sit easily under the heading of 'community studies' and, indeed, ideally their research findings would contribute to the definition of environmental standards which would protect each and every aggrieved individual, rather than some aggregated community. It may well be that the continued use of the phrase allows researchers (and administrators) to escape two genuine problems which it is absolutely necessary to face: the first, that at the present time it is possible to predict

individual responses to noise within only a very wide band of uncertainty; and the second that knowledge of the scale of individual differences in response has a vital role to play in helping us set community noise standards.

A considerable proportion of the literature now refers to dose-response relationships and it is, unfortunately, quite possible that similar considerations apply to this usage. In experimental toxicology, both dose and response are operationally-defined and objective phenomena: the response, death, is quintessentially so. In the case, however, of noise, this is far from being the case, since even the dose requires subjective definition. The objective acoustic datum is sound, the physical characteristics of which are measured by our acoustic technology: noise itself has to be psychologically defined. The response we measure, it should be understood, is even less objective and the attempt to describe the relationship between received noise and expressed reaction as a crude input-output process in which there are no intervening variables within the black box (the human being) is doomed to failure. The phrase dose-response relationship seems to encourage that simplicity of thought, and to remove the possibility of investigating human diversity.

These points will arise again in the review of the last five years' progress in this area because they are implicit criteria in that review, which is based on the search for:

(1) predictive relationships with noise sources other than aircraft and road traffic;

(2) methods of dealing with differences between the effects of different sources and their interactions;

(3) a concern for factors enabling us to shift from the analysis of grouped responses to those of individuals.

SINGLE NOISE SOURCES

To continue the general policy so far outlined, it is necessary to begin by indicating the noise sources which have so far received little or no attention. In view of the wide acceptance of the view that there is at present neither a noise index which receives total agreement in terms of its suitability for a universe of sources, or, even a commonly held limiting value of, say, L_{Aeq} it is perhaps surprising that no significant work has appeared in refereed journals in the last five years which relate to helicopters, general aviation, or to ground activity of aircraft. Nothing can be reported on noise from industry, construction, or entertainment, as far as community response is concerned. Urban and rural differences in response to transportation noise have most notably been investigated by Fields and Walker (1982) with regard to railway noise, but no work has been reported on the other sources of noise (aircraft, traffic) which exist in both town and country, or on the noise from agro-industry.

Infrasound or airborne vibration has continued to be neglected, and in the period under review only Leventhall's group (Broner and Leventhall 1982) have reported new work on low frequencies. The research investigation was laboratory-based and used the magnitude estimation technique for assessing both annoyance and loudness, which they found to be highly correlated. All noise indices tested were approximately similarly correlated with subjective response although it was concluded that dBB was possibly the most effective index.

Noise from neighbours has continued to be neglected, although Langdon et al (1981;1983) have reported that a small but significant proportion of the UK population living in postwar houses are bothered by noise through party walls and that the technically-derived Government standard correlated well with the percentage of respondents categorizing the insulation in each of four quality groups. It was also clear that the quality of insulation was salient to the respondents and that impact noise was particularly important. Fidell et al (1979) have reported an ingenious laboratory experiment in which the annoyance caused by low-level sounds was shown, in the case of one of three possible background spectra, to be better predicted by their detectability than by dBA or other indices.

Impulsive noise has received a fairly considerable degree of attention in the last five years: Seshagiri (1981), for example, has investigated community reaction to impulse noise from drop forges, producing correlation coefficients between community response and noise measurements of about 0.6. Hede and Bullen (Bullen and Hede, 1982; Hede and Bullen 1982) have followed Sorensen and Magnusson (1979) in investigating reaction to rifle-shooting ranges. The relations between exposure and reaction are fairly similar in both sets of investigations but the Australian researchers also took into account the noise sensitivity of respondents and their attitude to the presence of the rifle range.

Considerable progress in the understanding of railway noise effects has been made with the appearance of the results of the Southampton University study (Fields and Walker, 1982). This was a large-scale study carried out on more than 1400 informants and involving

approximately 2000 noise measurements. The Summed Annoyance Index (SAI) was found to correlate reasonably with the 24hr L_{Aeq} (r 0.42), a stronger relationship than with LDN, NEF, NNI, or dBB, dBD, or linear dB. There was no apparent need for day/night correction, or correction for background levels: and, in direct contradiction of Schultz (1978) railway noise was significantly less annoying than aircraft or road traffic noise, and SAI was a better correlate of exposure than % very annoyed. Of the personal characteristics of respondents, none showed any clear effect except that life-residence at the particular site conferred lower annoyance.

Aircraft noise continued to receive a great deal of attention. A Canadian group has reported the results of considerable investigation at Toronto International Airport and Oshawa Municipal Airport (Taylor et al, 1980; Hall et al, 1980). Their careful investigation of the effect of background traffic noise level on annoyance with aircraft noise (based on the analysis of correlations between noise annoyance and traffic noise exposure within the same level of aircraft noise) gave a largely null result. On the other hand, when unprompted reports of fear of crashes, of airborne vibration and air pollution were analyzed for their effects on aircraft noise annoyance within noise exposure bands (NEF), they were all found to have significant effects. Rylander's Swedish group (Rylander et al, 1980) have continued to argue for a reassesement of the interaction of overflight frequency and peak noise level. They conclude that the number of overflights only has an effect in the range up to 50 overflights per 24 hrs. Above this number the maximum noise level (dBA) which occurs at least three times in the 24 hrs is claimed to best represent community response. Taylor et al

(1981, op cit) have attempted to investigate the effect of the number of overflights in comparison with the effects of peak noise level by looking at two airports with different characteristics: both airports showed significant correlations between NEF levels and % annoyed, % sleep disturbed, and % suffering speech interference. For the same NEF, however, the smaller airport of the two always generated more disturbance, thus confirming the operation of different models for varieties of the same noise source.

In the field of road traffic noise there is also a significant Canadian contribution (Bradley and Jonah, 1979). Their major aim was not to elucidate the primary relationship between traffic noise exposure and community response, [illegible] to clarify the [illegible] of [illegible] road type, community size and socio-economic status as variables intervening between exposure and response. This they did by selecting a sample containing 4 noise levels, 2 levels of socio-economic status, 3 sizes of community, and 3 types of housing. Flat-dwellers were more annoyed than other groups at high noise levels, and it was suggested that this might be due to their having better visual contact with, and therefore better knowledge of, traffic flow. Road type appeared to interact with socio-economic status so that freeways caused more annoyance to high status respondents than to lower status informants, at high noise levels. There also appeared to be lower levels of annoyance in small communities than in larger (although smaller communities contained only separate houses and regular roads). Griffiths et al (1980) investigated seasonal effects of traffic noise on inhabitants of houses fronting on to suburban roads and exposed to 18hr dBA L_{10}s between 57 and 81. This study showed a complete absence of seasonal

effects on dissatisfaction, and, indeed, of differences between households based on window-opening practices. Nemecek et al (1981) investigated the proportion of the population highly annoyed as a function of noise exposure in a number of Swiss towns and found a good fit with the synthesis of social surveys reported by Schultz (1978).

A number of researchers have attempted to investigate traffic noise annoyance in the laboratory. Cermak (1979) used the Multi-Dimensional Scaling technique on paired comparisons of similarity and aversiveness of 13 45s samples of traffic sounds. The major determinants of the subjective judgements were complexity (which was not specifiable in physical terms)and variability (which was not the standard deviation) of the noises. L_{Aeq} was the best predictor of aversiveness. Ohrstrom et al (1980) investigated reaction to recordings of the noise from mopeds, trucks, trains and aircraft with the same peak dBA but different L_{Aeq}. L_{eq} was the best predictor of subjective reaction and differences between different vehicles at similar L_{eq} values were observed.

The great majority of studies of traffic noise annoyance relate to the specific subpopulation of people in their homes, but Sargent et al (1980) have reported a study of the disturbance caused to school teachers at their work. The correlation between teachers' responses on a 5-point scale of 'bother' and the dBA L_{10} during the school day was very high and teachers appeared to be more sensitive to noise disturbance than householders. It is possible that the restriction of possible contexts (one classroom/teacher; the largely auditory task of teaching) is the reason for this finding: if so it is possible that contextual restrictions could beneficially be placed on respondents in household surveys.

COMPARISONS BETWEEN NOISE SOURCES

Just within the time-period covered by this review falls a comprehensive attempt at the synthesis of the results of a large number of previous research investigations which is so ambitious and important that it cannot be dealt with in the format of the brief abstract: Schultz's review of social surveys on noise annoyance (Schultz, 1978). Schultz reviews a very large number of community noise surveys relating to transportation noise sources, with the aim of reconciling the differences between them so as to reveal a common data base. He has no reservations about having had to make arbitrary and subjective judgements of his own in doing so. Kryter (1982) has criticized the synthesis on grounds which have not received Schultz's acceptance. Both methodological and empirical points can be raised which cast doubt upon the validity of Schultz's procedures, and perhaps on some of the changes of attitude among noise researchers which seem to have followed the advent of Schultz's synthesis.

Since the beginning of this field of research activity it has been recognized that attitudes to noise are continuous, scalable variables and many attempts have been made to construct methods of measuring these attitudes. Schultz, however, favours the treatment of attitude data as categorical: highly annoyed or otherwise. This is an extremely crude use of complex data and the crudity is manifold:

1. the reduction of ordinal or possibly interval data to classificatory;

2. the failure to perceive that a statistical distribution (of, in this case, annoyance scores) can minimally be described by a measure of central tendency and one of dispersion. While a distribution may

need more than this to be characterized adequately it cannot require less;

3. the assumption that there is a fixed threshold for annoyance which is adequately defined entirely in terms of the respondents' verbal behaviour pre-empts policy decisions;

4. the avoidance of the problem of individual differences;

5. the choice of a relatively extreme criterion (highly annoyed) as the basis of the single descriptive statistic for the attitude data. This leads to a greatly increased statistical error in the prediction of annoyance in practical situations, therefore reducing the possibility that the procedure can achieve what it in large part sets out to do. This point is sufficiently important for it to be worthwhile to consider it further before going on to evaluate the reasoning which Schultz advances.

Every social survey is based on the idea of sampling: small samples are taken of the population exposed to each of several noise levels and regression lines are constructed relating attitude and noise exposure. The size of the sample is normally in the range 1 to 100, and for the sake of this argument is taken to be 50 Schultz recommends estimating the proportion of the population highly annoyed on the basis of the sample data. Griffiths and Delauzun's (1977) results can be used to exemplify the procedure recommended. At the noisiest site in that study the 18hr dBA L_{10} was 80 and the mean dissatisfaction score approximated to 5.5; at the quietest, by contrast, the relevant figures were about 60dBA and 3.5. The standard deviation in dissatisfaction was approximately 1.75: the statistical distributions were truncated normal. With this information it is easy to consult the table of the unit

normal curve and read off the percentage exceeding any value of the score distribution which it is desired to use as a cutting-point.

The % annoyed should relate to respondents scoring over the named midpoint of each interval, rather than its lower band, 5.5 or 6.5. Table 1 gives the percentages above each of these cutting-points for the two sites:

TABLE 1 PERCENTAGE OF POPULATION HIGHLY ANNOYED

	SCORE			
	5.50	6.00	6.50	7.00
Site 1	14%	8%	5%	0%
Site 2	50%	38%	27%	18%

The standard error of an estimate of a proportion is given by the square root of

$$\frac{p(1-p)}{n-1}$$

Where p is the proportion and n the sample size.

Table 2 gives the resulting confidence limits for each percentage:

TABLE 2 CONFIDENCE LIMITS FOR PERCENTAGES IN TABLE 1

	SCORE			
	5.50	6.00	6.50	7.00
Site 1	4-24%	0-16%	0-11%	0%
Site 2	36-64%	24-52%	15-39%	7-29%

It can be seen that for the quieter site all predictions (and sample estimates) for percent highly annoyed, however defined, are extremely hazardous. For the noisy site they are merely hazardous: only in the case of the 50th percentile criterion does the ratio of highest to lowest estimate fall below 2 : 1. By comparison the confidence limits for the medians (5.5 and 3.5) are 4.9 to 6.1 and 2.9 to 6.1, and for means 5.0 to 6.0 and 3.0 to 4.0.

It must be concluded that the use of these extreme categories as the sole descriptors of distributions of noise annoyance scores is open to very severe criticism.

What are the justifications which Schultz offers for his selection? He suggests first of all that there is less scatter in extreme noise exposure, but makes no mention of the possible influence of the ceiling effect on this (since our scales have upper limits it becomes impossible to maintain the distance between the lowest score and the highest at high levels). Data available to the author (Griffiths and Delauzun 1977 op cit) indicate that this statistical artifact does not have an effect on distributions at levels as high as 80dBA 18hr L_{10}, suggesting that it is unlikely to be of any significance in most circumstances. Schultz goes on to suggest that the 50% of the population below the median at any level of noise exposure have not heard the noise the other 50% complained of, and that therefore their removal would increase correlations between exposure and attitude. Griffiths and Delauzun (1977, op cit) present data on the first half of this argument: by use of a filter question they were able to identify those who did not hear traffic noise at home at each of their four sites: at 80dBA L_{10} 11% of the respondents claimed not to hear the traffic noise while at home and yet 50% of the remainder of the sample at that location scored below the median of 5.6 and did report hearing the noise; at 70dBA 7% of respondents claimed not to hear the noise and 50% scored below the median of 4.8 while reporting hearing the noise. The Schultz suggestion thus fails an empirical test. As to the second point, that of improved correlation if those below the median are excluded from consideration, this has also received a direct empirical test. Using the data presented in Griffiths, Langdon and Swan (1980), correlations were run

between attitude and exposure for those scoring above the median at each level of exposure and those scoring below. The study involved more than 1300 interviews at noise exposures from traffic between 52 and 79 dBA L_{eq}. The correlation coefficient was higher for the group above the median than for the total group (r = 0.60, n = 116, compared with r = 0.42), but so was the correlation coefficient for the group below the median (r = 0.59, n = 106). Thus, the Schultz hypothesis is confirmed as a statistical artifact: if the variance within each sample is artificially reduced, without reducing the range of noise exposure, then the correlation is improved.

Finally, we have to consider whether there is any clear evidence that transportation noise sources can be treated as homogeneous in their effects. We have already seen that Ohrstrom et al (1980) have shown that recordings of different transportation sources with similar or identical L_{Aeq} levels are responded to differently by the same groups of subjects. Fields and Walker (1982) have shown that aircraft and traffic noise are responded to more unfavourably than train noise of the same level. The case for treating different noise sources differently seems therefore to be adequately made out. Ahrlin and Rylander (1979) have investigated the disturbances suffered by people experiencing high levels of annoyance from aircraft, tramways, road traffic and trains and, although they have made no attempt to equalize between these sources in physical terms, have shown that the patterning of disturbance (as between speech disturbance, sleep disturbance, and awakening) is different for the different sources. It is therefore vital that some measure of annoyance independent of source is used in comparative research and possibly some nonverbal measure of aversiveness as developed by Cermak (1979), Fuller and Robinson (1980), Molino et al (1979) or Vallet et al (1980).

INDIVIDUAL DIFFERENCES AND OTHER PSYCHOLOGICAL FACTORS

Since about the mid-70s there has been a change in emphasis in the way in which psychological aspects of noise nuisance have been investigated, away from the multivariate analysis of data gathered to elucidate the dose/response relationship and towards the specifically designed field experiment or quasi-experiment.

Griffiths and Delauzun (1977, op cit) investigated the reliability of their dissatisfaction scale, which they showed to be significant but only moderate in magnitude. Griffiths et al(1980) replicated this finding for another sample of sites affected by traffic noise and Hall and Taylor (1982) extended the replication into a greater variety of scales, and with the addition of aircraft noise. Griffiths and Delauzun also showed that reliable personality measures could not be used to explain individual differences in less reliable annoyance scales. Griffiths et al (op cit) demonstrated that the reliability of single element ratings could be improved by repeated measures on the same respondents, but the combination of repeated measurement and stable personality measures has not yet so far been tried. Weinstein (1978) investigated longitudinal effects in dissatisfaction with dormitory noise in groups of high and low sensitivity students. The dissatisfaction of sensitive students increased with exposure time. He also showed a fairly wide range of weak personality relations with sensitivity. In a later paper (Weinstein 1980) a rather similar longitudinal study, this time concerned with highway noise, was reported and gave evidence of the existence of a general characteristic of 'criticality' operating as an intervening variable between noise exposure and attitude.

The past five years have also seen a reawakening of interest in the

phenomenon of adaptation. Vallet et al (1978) found that there was no change in the distribution of annoyance scores over a two-year period after the opening of a new autoroute. Weinstein (1982) carried out a sophisticated before-and-after study of a new highway, and concluded that no adaptation in annoyance took place between 4 months and 16 months after opening. These results are consistent with internal analyses of earlier data including length of residence statistics, but there is an apparent and as yet unresolved conflict with the finding of Langdon and Griffiths (1982) that in the case of both road by-pass schemes and the erection of noise barriers only before-the-event data are easily predictable from steady-state databases, while 'after' data seem to follow different regularities. If these findings are taken together with the absence of seasonal effects on road traffic annoyance (Griffiths et al, 1980 op cit), it is possible that further investigation will confirm the existence of relevant perceptual constancy phenomena.

In recent years there has also been a new interest on the part of social psychologists in the effects of urban noise on such social behaviours as cooperativeness and attentiveness (Jones et al., 1981).

CONCLUSIONS

Steady progress has continued in improving our understanding of community reaction to road traffic, aircraft and railway noise. However, other fields, mapped out as long as twenty years ago (industry, construction, entertainment and rural noise, as well as specific aviation-related areas such as ground-running noise and helicopter noise), continue to be neglected.

The shift from scientific interest and information concerning community response to interest and information about individual human

response is being pursued with insufficient vigour and there are signs of a retreat in the face of this complexity into dangerously simplistic models of human response.

It is now becoming clear that the problem of differences in response to noise from different sources is a complex one, and that the combination of sound effects is even more so: if it is to be achieved it will be on the basis of summating human experience and not sound energy.

While there are very good reasons to persevere with the traditional response scaling and analysis tools, there is the beginning of a lively interest in other psychological measurement techniques, together with improvements in reliability and validity which will enable higher quality research into individual differences. There are also indications that response to environmental changes needs particular attention and that psychological factors like the perceptual constancies may have practical implications for policy.

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INTEGRATION OF MULTIPLE AIRCRAFT NOISE EXPOSURES OVER TIME BY RESIDENTS LIVING NEAR U.S. AIR FORCE BASES

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INTRODUCTION

A number of environmental noise indices have been utilized for years to describe the cumulative noise impact on residential communities. Based largely on engineering tradition and acoustic instrumental convenience, practically all of these noise indicators assume that time varying numbers and levels of noise events are logrithmically integrated. Some measures, such as Ldn, CNR and NEF [1)2)] use a day/night penalty of 10:1, based on the observation that sleep interference during the night is rated as quite annoying. Recently Ollerhead [3)] and others have questioned the validity of the amount of the day/night penalty, but for lack of sufficient contrary evidence could offer no more valid substitute noise descriptor. But even he assumed the simple energy summation of events. In all of these past 30 years of community noise research, [4)] no study was ever designed to determine just how different people integrated time varying noise from different sources with different levels, spectra, durations, numbers of occurences during different times of the day, evening and night. When people are asked to rate their noise environments,

they have little difficulty in selecting a point on a noise or annoyance intensity scale. But if asked to explain how they weighted all the time varying variables in order to arrive at their rating, they are unable to do so. It was decided, therefore, that an indirect approach was needed to unravel this very complex noise integration process.

The U.S. Air Force has a very practical need to have an accurate noise predictor in order to provide healthy on-base and off-base residential environments. The location of on-base housing facilities and land acquisition of areas located near Air Base facilities require an objective and accurate noise predictor to avoid creating noise environments that are harmful to the health and welfare of its own personnel and its civilian neighbors. In awarding Columbia University a contract (F-33615-80-C-0527), an opportunity was provided to design a special study to attempt to unravel just how people unconsciously combine their time varying noise experiences.

STUDY DESIGN

Tyndall Air Force Base is the repository of operations and acoustics data for all Air Force bases. The plan was to select a number of different Air Force bases with a wide range of numbers and types of day/night operations. With the assistance of Major Jerry Plummer, of Tyndall Air Force Base, the many types of air bases were separated into different analytical groups. Noise contour maps (Ldn) were examined to see that there were population centers located at varying distances from flight tracts to afford different airplance altitudes and noise levels exposures. Ten different air bases were tentatively selected from these strata to represent the diversity of Air Force operations. These selections were then reviewed by Gary Vest of USAF headquarters, Jerry Speakman and Dr.

Charles S. Harris of Wright-Patterson AFB and personally visited to be certain that the data at Tyndall were up to date and accurate.

At each Air Base, five small segments (about 400-600 feet in a single direction) were purposively selected along flight tracts and at different distances from the Air Base; three were usually off-base areas and two were on-base military housing. A listing was made at each segment and 36 addresses were randomely selected and assigned to 4 interviewers. Each interview required answers to about an hour of skillfully embedded questions in a traditional manner about many different neighborhood issues, such as schools, shopping, etc. and many different noise sources, including aircraft flyovers and ground run-ups.

At each segment, a Digital Acoustics DA 607P automatic noise recorder was located for about 10 days to record and print each actual noise event above a threshold of 65-70 dBA. For each event the recorder tape printed the maximum dBA, duration down 10 dB, time of maximum, and integrated Sound Exposure Level (SEL). In addition, the recorder calculated the integrated hourly noise levels (HNL), and the 24 hour Leq and LdN. By arranging the tapes from the array of recorders at different locations, the levels and durations of peak and time of peaks were compared to separate aircraft events from cars, trucks and other acoustic occurrences.

The responses from the interviews provide a variety of measures of resident perception, reported activity interferences and annoyance with each noise source heard. In the analysis, these responses are correlated with the actual recorded physical noise exposure measures overtime to indicate how the residents uncousciously responded and integrated their noise experiences.

RESULTS

Due to unforseen and unavoidable legal and administrative difficulties, three of the Air Force bases originally selected had to be excluded from the study. In addition the U.S. postal service lost half the completed interviews of another Air Base, with the result that a total of 942 usable interviews from seven Air Bases are included in this study as shown in Table 1.

TABLE 1

Number Completed Interviews Included in Study

Air Base	Total	Segment				
		Off Base		On Base		
		1	2	3	4	5
Dover	71	36	3	32	0	0
Mather	158	32	18	36	36	36
George	180	37	36	35	36	36
March	155	11	36	36	36	36
Marana	128	33	32	31	32	0
Carswell	180	36	36	36	27	45
Pope	70	0	0	0	36	34
Total	942	185	161	206	203	187

Even with the unfortunate loss of the three Air Bases, the range in physical exposures included in the study is substantial. For average Leq it was 47-79. For average Ldn, the range was from 47-81. The range for average HNL during the day was 46-74; for evening, it was 44-71; and for night, it was 34-59.

Day (0700-1900 hours), Evening (1900-2200 hours) and Night (2200-0700 hours) were defined in traditional time periods, and these groupings

were generally confirmed by answers from the survey. About one-third of the residents said they went to sleep from 2200-2300 hours; another 38% from 2300-2400 hours. Only 12% said they usually went to bed before 2200 hours and 15% after 2400 hours.

The representativeness of the aircraft operations during the field recordings was also verified from reports of Air Force personnel and residents. Over three-fourths of all residents said that operations during the past two weeks were about the same as usual; 8% said they were more and 15% said they were less than usual. A more detailed description will be included in a future Air Force report.

Time will only permit a very brief summary of the study's finding. The following ten different cumulative noise measures were calculated from the 24 hour, 10 day noise recordings at each Air Base:

1 - Average 24 Ldn

2 - Highest 24 hour Ldn

3 - Average 24 hour Leq

4 - Highest 24 hour Leq

5 - Average number flights by dBA peak for day, evening and night (5 db intervals)

6 - Highest number flights by dBA peak for single day, evening and night (5 db intervals)

7 - Average highest sound exposure level (SEL) by time of day

8 - Highest single sound exposure level (SEL) by time of day

9 - Average integrated Hourly Noise Level (HNL) by time of day

10 - Highest integrated Hourly Noise Level (HNL) by time of day

Each of these ten physical measures were correlated (Pearson) with two summary responses of annoyance with aircraft flyovers. The first measure was an answer to a single question, after a half hour of direct

questions on possible effects of aircraft flyovers on desired activities such as communication, sleep, rest, TV viewing, vibrations and concentration. The other was the traditional annoyance index based on reported interference with the above activities and resulting annoyance (scale of 0-9) with each unwanted interference. As in most previous studies, the correlations with the combined activity index of annoyance were higher than with the single question responses, so only the index scores will be presented at this time.

The best predictor of annoyance proved to be a multiple correlation of the highest number of flights by peak dBA, by day, evening and night periods. The second best physical predictor, just slightly less effective was the average number of flights, by peak dBA and time period. Over a third of total individual variance in annoyance responses is explained by the combination of number and peak dBA by time of day, compared to only 8% for Ldn and 14% for average Leq. The Pearson correlation coefficients for the 10 physical measures are presented in table 2. This finding was also first discovered in a controlled laboratory study conducted by Columbia University in 1977.[7)]

Samples of residents near JFK Airport, N.Y., were first interviewed in their homes and their integrated annoyance responses were recorded. Then, invited to a living room type laboratory, they judged different numbers and peak levels of overflights that were calculated from operations reports for their areas as below average, average, peak and above the peak number operations per hour at JFK. The laboratory judgments of annoyance with the peak number of operations was closest to the integrated field interview responses. This finding wasn't widely discussed because it involved integration of only half hour noise exposures and was so different from the expected use of averages in acoustic indexes.

Table 2

Correlations Between Physical Acoustics Descriptors and Reported Annoyance with Aircraft Flyovers

Physical Measure	Coefficient R	Explained Variance R^2
Average Ldn	.28	.08
Highest Ldn	.28	.08
Average Leq	.37	.14
Highest Leq	.28	.08
Average number x peak dBA x Day, Eve, night	.57	.32
Highest number x peak dBA x Day, Eve, night	.58	.33
Average SEL by Day, Eve, Night	.41	.17
Highest SEL by Day, Eve, Night	.40	.16
Average HNL by Day, Eve, Night	.42	.17
Highest HNL by Day, Eve, Night	.45	.21

It might be of interest to examine in a little more detail the relationships between average Ldn and low, moderate and high annoyance. The definitions for different degrees of annoyance are discussed later and were carefully developed by detailed item analysis in previous studies.

As shown in table 3, there is an inconsistent pattern of relationships between Ldn and highly annoyed respondents. There is a growth of annoyance with higher Ldn exposures, but it is irregular. This irregularity can be greatly reduced if we perform some statistically acceptable refinements in the data, and if we make certain administrative assumptions. I am indebted to Dr. Harris of the U.S. Air Force for suggesting these additional analyses. First we must make the administrative assumption that we are only interested in protecting the highly annoyed from noise pollution. This eliminates from our concern about 90% of the population at 55 Ldn, 70% at 70 Ldn and over 30% at the highest exposure included in

this study, 85 Ldn. It is hard to believe that the authorities can ignore 50% of the moderately annoyed who find noise unacceptable. Secondly, if we perform a logistic transformation of the high annoyance responses, we get a curve that still varies considerably from Shultz's curve 30% at 85 Ldn, 11% at 75 Ldn and 5% below 70 Ldn. But if we drop the three values below Ldn 50 which had unexpectedly large " highly annoyed responses on the assumption they are "outliers", out of line with the rest of the data, and three additional data points with no highly annoyed responses, we end up with 10 data points and a curve that is very close to Schultz's curve. The advantage is in a simpler prediction formula but the disadvantages are the assumptions described above. Furthermore, our more complex number and level scheme accounts for individual variability among about 1000 residents, while the Harris analysis is based on limited group variability. Finally, our equations predict the full range of annoyance responses, so authorities can determine how much protection to give to how many people. Our final report will discuss the comparison of Ldn curves in greater detail.

As reported in practically all other community noise surveys, other personal attitude and experience differences are extremely important in predisposing acceptance or annoyance with identical noise exposures. Some of the correlations between selected personal variables and the index of activities annoyance responses are shown in table 4.

Fear of crashes is a traditional index based on four standard questions, dealing with planes flying too low, danger of crashes, etc. Belief that airplane operations are harmful to health is a new index based on seven direct questions (give headaches, feel tired, nervous, irritable, cause hearing difficulties, make other health problems worsen, and feel depressed). Readiness to complain indicates a person's willingness to express annoyance and is based on seven possible overt acts. This

TABLE 3

Comparison of Degree of Reported Annoyance and Ldn Level

Average Ldn		Per Cent of Reported Annoyance		
	Resident Total	Low	Moderate	High
45-49	105	75	6	19
50-54	99	91	1	8
55-59	174	84	7	9
60-64	222	68	10	22
65-69	188	72	11	17
70-74	81	64	10	26
75-79	72	60	15	25
80+	36	17	8	75

TABLE 4

Correlations Between Reported Annoyance and Selected Personal Variables

Personal Variables	Correlation Coefficient R	Explained Variance R^2
Fear of Crashes	.69	.47
Harmful Health Effects	.63	.40
Readiness to Complain	.47	.22
Misfeasance	.26	.07
Length of Residence	.09	.01
Relatives at Base	.05	*
Noise Sensitivity	.15	.02
Income	.09	.01
General Satisfaction with Neighborhood	-.32	.10

* less than 1%.

index is especially important to account for "patriotic" Air Force feelings that it is not right to complain about Air Force operations. By imputing a low value to this factor, the findings may be projected to civilian type situations. Feelings of misfeasance is an index indicating that the authorities can do more to reduce the noise and annoyance but choose to ignore the well being of the residents and fail to act.

By including just three of the more important personal variables, fear, health hazard and readiness to complain, in a multiple correlation equation with the best fit of physical descriptors, high peak dBA by time period, a multiple correlation coefficient of R=.81 is achieved, explaining over two-thirds of all individual variance in annoyance responses. To reduce the length of the equation, without greatly changing its efficiency, the number of physical categories are collapsed into 9 groups, and the multiple correlation coefficient is reduced to R=.80. Table 5 presents the contributions of each variable to the multiple regression equation.

The multiple regression equation consists of the constant -2.675832 plus the "B" values times the estimated number of flights for each dBA peak value, during each time period, and the estimated index values for each personal variable. While the prediction equation has 12 items which is not as simple to use as a single physical index, it clearly is more related to human annoyance and can be defended as more valid.

The annoyance index values range from 0-54. From previous studies (6) a score of 0-15 indicates little or no annoyance which is generally acceptable to over 95% of all persons; a score of 16-25 indicates moderate annoyance which is acceptable to about half of all residents. A high score of 26-54 indicates high annoyance which is acceptable to less than

TABLE 5

Multiple Correlation Between Annoyance With Airplane Noise and Physical Exposure and Selected Personal Variables

Variable	Multiple R	R^2	"B" Values
1. Hi Peak Day (70-84.9 dBA)	.037	.001	.01237161
2. Hi Peak Day (85-99.9 dBA)	.404	.163	.1693247
3. Hi Peak Day (100+ dBA)	.406	.165	-.08509909
4. Hi Peak Eve (70-84.9 dBA)	.409	.167	.05027401
5. Hi Peak Eve (85-99.9 dBA)	.443	.196	.1189223
6. Hi Peak Eve (100+dBA)	.511	.262	1.109613
7. Hi Peak Night (70-84.9 dBA)	.512	.262	-.02526349
8. Hi Peak Night (85-99.9 dBA)	.513	.263	-.03909553
9. Hi Peak Night (100+)	.528	.278	1.089908
10. Fear of crashes	.759	.576	.7403936
11. Harmful Health Effects	.791	.626	1.412787
12. Complaint Readiness	.800	.639	.1500799

10% of all such exposed persons. The above new prediction equation will permit planners and administrators to more accurately predict community response to estimated noise exposures. By inserting low, moderate and high values for the personal factors, a range of predictions and values can be calculated. Future parallel studies of civilian airports should test the usefulness of this prediction equation for more generalized civilian use.

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HUMAN RESPONSE TO AIRCRAFT AND OTHER NOISE EVENTS

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INTRODUCTION

Considerable progress has been made during the last 5 years in evaluating and developing various noise metrics for quantifying discrete noise events. Stimulated by both national and international certification issues, aircraft noise in particular has been the subject of considerable research. This paper describes recent research studies sponsored by the NASA to improve the quantification of noise events. Results of both laboratory and field studies are discussed which relate to community and passenger response to aircraft noise and the human detectability of the relatively low frequency noise associated with wind turbine generators.

RESULTS

Propeller Aircraft Metrics

Increasing interest in propeller airplanes for business, commuter and energy-efficient long-haul operations has raised questions about the performance of various noise metrics for

quantifying the annoyance of propeller aircraft relative to turbofan (jet) powered aircraft. Two experiments are reported in Reference 1. The first examined the subjective response to propeller airplanes with maximum takeoff weights greater than or equal to 5700 kg and the second examined airplanes with weights equal to or less than 5700 kg. Figure 1 illustrates results for the two weight classes in terms of the effective perceived noise level (EPNL) (metric used in the noise certification of jet aircraft). Laboratory test subjects rated the annoyance of the heavy propeller aircraft

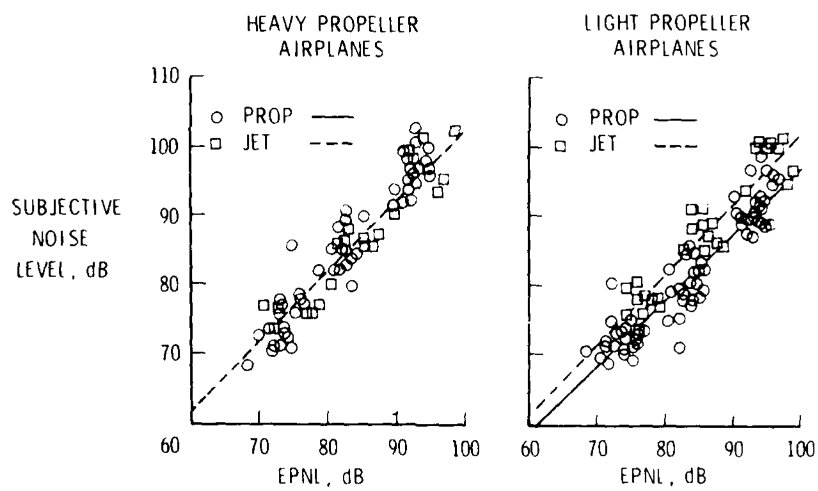

Fig. 1. Quantification of propeller and jet airplane

virtually the same as the annoyance of the jet aircraft. However, for equal values of EPNL, the light propeller aircraft were judged to be about 4 dB less annoying than the jet aircraft. This difference between the propeller and jet aircraft noise was found to be even greater (6 dB) when the noise was quantified in terms of A-weighted sound level (LA).

Helicopter Metrics

An evaluation of current noise metrics for quantifying the annoyance of helicopters is reported in Reference 2. Subjects judged the annoyance of 89 helicopter recordings and 30 conventional takeoff and landing (CTOL) aircraft. Results are summarized in Figure 2 in terms of five common metrics: the A-weighted level, LA; the D-weighted level, LD; the perceived noise level, PNL; and PNL with tone corrections, PNLT, and impulse corrections, PNLTI. The predictive ability of each metric is described in terms of the standard deviation

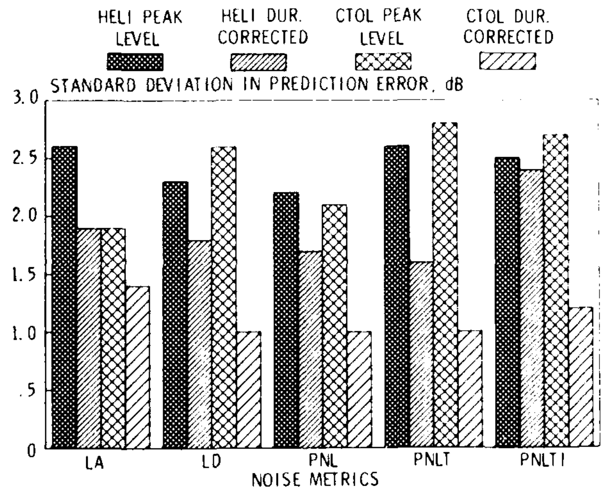

Fig. 2 - Quantification of helicopter and jet airplane noise.

in prediction error of subjective response for each vehicle class. The major findings were that EPNL (PNLT with duration correction) predicted annoyance as well as or better than other metrics and that impulse corrections provided no improvement. Although not shown on the figure, the helicopter

noises were found to be slightly less annoying than the CTOL noises at the same EPNL level (the equivalent of 4 dB less).

Aircraft Interior Noise Metrics

In addition to community noise effects, interest in propeller and rotary wing aircraft has raised questions concerning passenger acceptability criteria. Of particular interest are methods for describing the cabin noise when strong tonal components are present and secondly for describing the interactive effects of noise and vibration on passenger acceptance. These two issues are examined and reported in References 3 and 4. To examine the quantification of tone/boundary layer noise combinations, tones ranging in frequency from 80-315 Hz were combined with boundary layer spectra and rated by test subjects in an anechoic chamber. The annoyance was determined as a function of noise level for both the boundary layer noise and the tone/noise combinations. The differences in noise level required for the different stimuli to produce the same annoyance were determined for a variety of noise metrics. From these differences "tone penalties" were determined for each tone-noise combination. Tone penalties are shown in Figure 3 as a function of the tone/noise ratio for two metrics commonly used to describe aircraft interior noise, LA and SIL. For the example chosen, the tone penalty (error) in terms of LA is seen to be quite small whereas the penalty in terms of SIL becomes relatively large for the higher values of tone/noise ratio. As pointed out in the paper, the magnitude of the tone penalties is dependent upon the shape of the boundary layer noise spectrum.

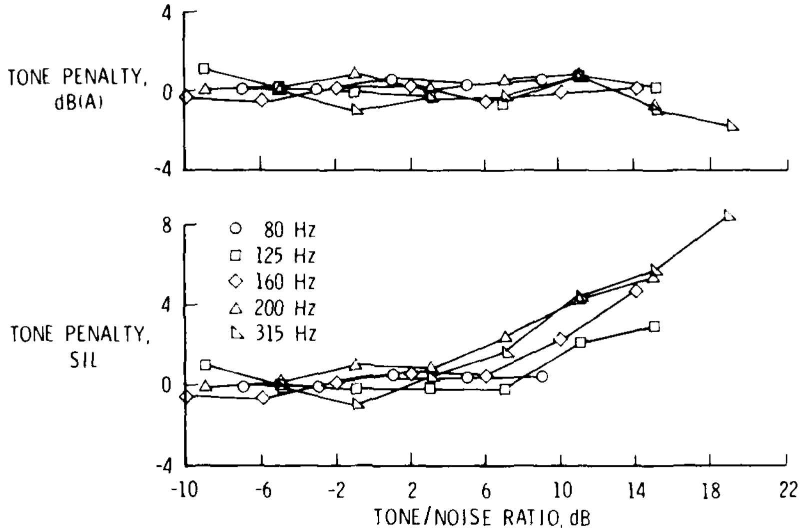

Fig. 3 - Quantification of propeller aircraft interior noise.

The interior environment of vehicles such as helicopters is affected by relatively high levels of vibration in addition to the noise. Models for describing and/or assessing human response to combined noise and vibration environments have been under development for several years and were recently evaluated for helicopter environments in a study involving the response of pilots to a wide range of noise/vibration combinations presented in a laboratory simulator (Reference 4). The tradeoff of noise and vibration is shown in Figure 4 in terms of values of LA and vertical acceleration g_{rms} that produce constant values of comfort. As can be seen, the influence of vibration on human comfort is highly dependent upon the noise level; the influence being small at high levels of noise and more pronounced at the lower

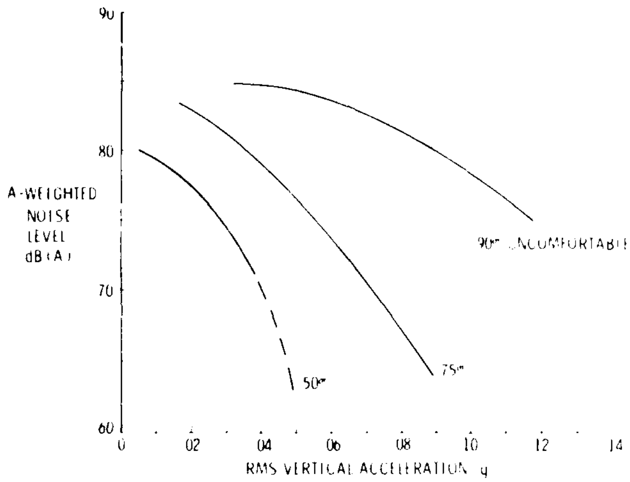

Fig. 4 - Noise and vibration tradeoff for helicopter stimuli.

levels. A mathematical model for predicting the discomfort of combined noise and vibration is described in Reference 4 and the results have recently been incorporated into a ride quality meter which is undergoing checkout at the present time.

Community Noise Effects

The studies discussed in the previous sections as well as most studies involving close control of the acoustical stimuli have been conducted in a laboratory setting. A new methodology which in effect combines techniques used in the laboratory with those used in conventional community surveys is described in Reference 5. The approach involves simultaneously recording the noise of individual noise events along with the response of community residents within their homes. The technique is felt to have advantages over laboratory

studies for determining the influence of factors where context may be important such as time-of-day effects, and aircraft type differences. The relationship between out-of-doors aircraft peak noise level (LA) and the response to individual flyovers is summarized in Figure 5. The linear regression line which best fits the 1164 individual ratings of the flyovers as well as the means of the responses in each noise

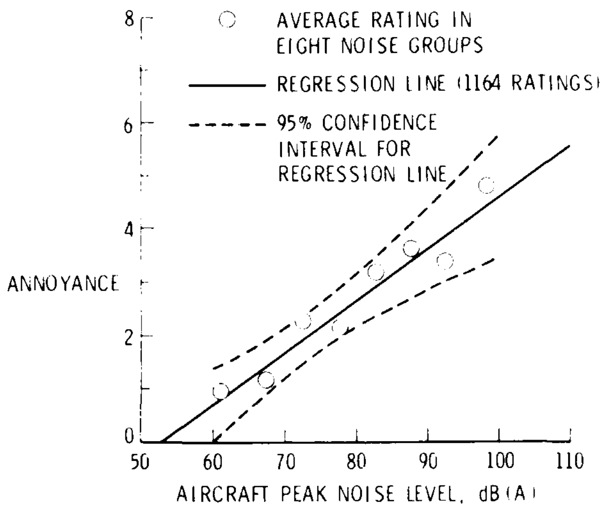

Fig. 5 - Resident annoyance response to aircraft noise events.

group are presented. The precision of the field technique as illustrated by the breadth of the confidence interval is compared in detail with laboratory precision in Reference 5. It is interesting to stratify the data making up the dose-response relationship of Figure 5 by aircraft type, ambient noise level and time of day as presented in Figures 6(a) through 6(c).

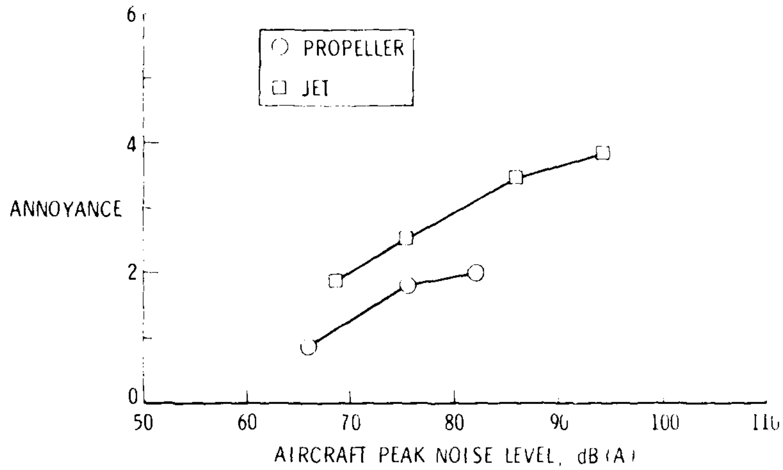

Fig. 6(a) - Type of aircraft.

In Figure 6(a), the annoyance of the propeller aircraft is seen to be less than the jet aircraft which is consistent with the laboratory findings previously discussed in Figure 1. The effects of ambient noise are shown in Figure 6(b) where reduced aircraft noise annoyance is seen in high ambient noise environments which is consistent with several aircraft noise rating laboratory experiments, References 6 and 7 for example. The dependence of annoyance on ambient noise level is often cited as a justification for utilizing a day-night weighting scheme.

The study design (Reference 5) made it possible to control for ambient noise level and study time-of-day effects directly. That is, noise rating sessions were equally divided between three time periods; morning, afternoon, and evening. The results by time period are presented in Figure 6(c).

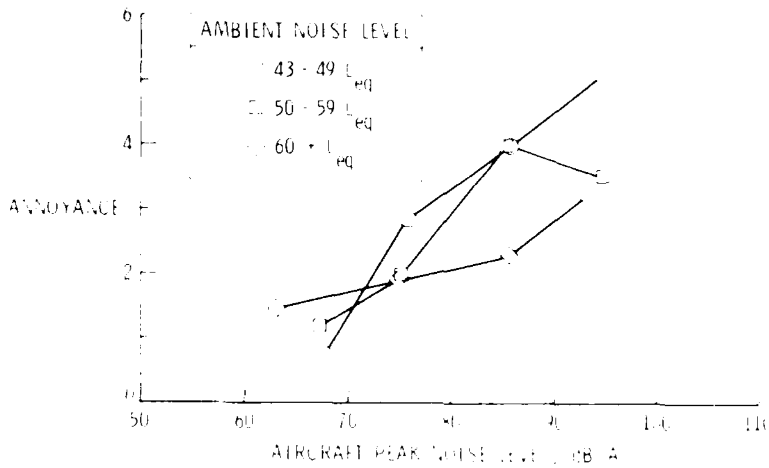

Fig. 6(b) - Ambient noise.

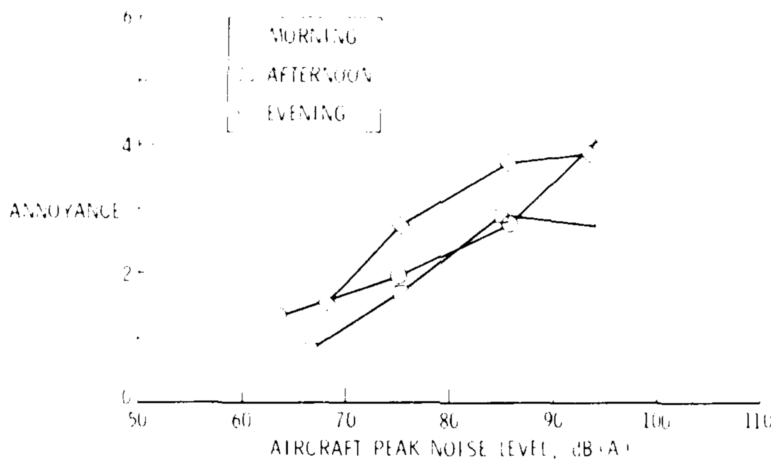

Fig. 6(c) - Time of day.
Effect of mediating variables of annoyance.

Although it was not established to be statistically significant, the graph of the reactions at different times of day suggest that events occurring in the evening are more annoying (an equivalent of 10 dB) than morning and/or afternoon periods.

Although the results of this particular study were less precise than desired, the use of field-laboratory studies shows promise particularly for cases where psychological, attitudinal and other nonacoustical factors (time of day, for example) play an important role.

Impulsive-Noise Detectability

As part of NASA's energy research, several large wind powered generators have been installed throughout the country to examine performance and other operating characteristics including the noise and any noise induced building vibrations resulting from the operation of such machines. Several research studies have been conducted to study the human response to the low frequency impulsive type noise (blade-tower/wake interaction) generated by certain configurations and a guide has been prepared to aid in the design and siting of such machines for community acceptability, (Reference 8). The guide suggests that, as a goal, the noise and vibration be below the human perception threshold of noise (Figure 7) and vibration (Figure 8). The establishment of these thresholds is based upon subjective tests and data analyses described in Reference 8. In practice, it is suggested that the narrowband and the one-third octave band spectra of the noise be compared to Figures 7 and 8. If the levels of the noise are above the threshold values (which is dependent upon the ambient level) estimates of the community response may be determined (depending upon the level above threshold) from the ISO Standard for Community Response to Noise.

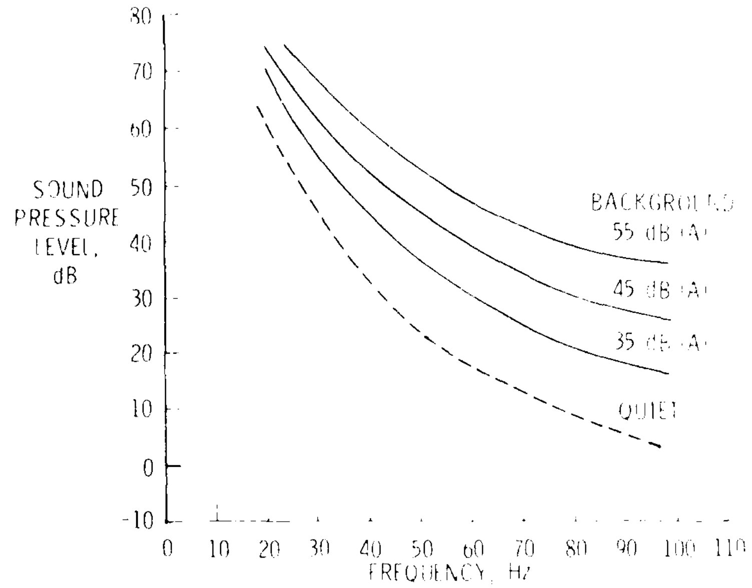

Fig. 7 - Detection thresholds of low frequency noise.

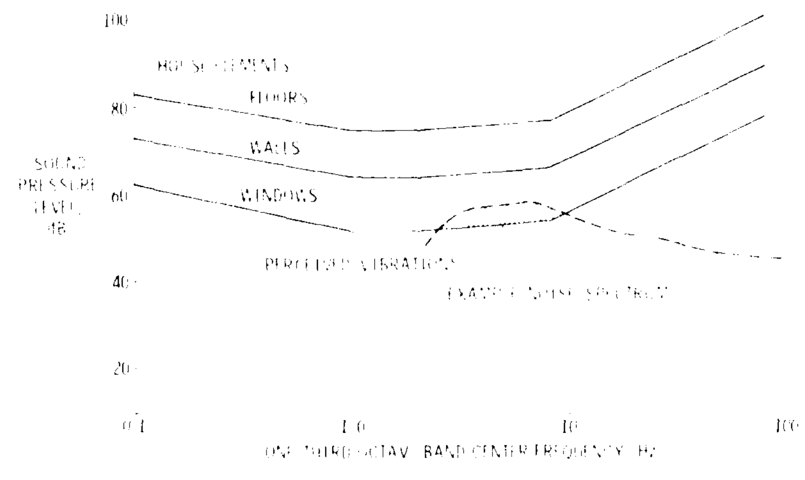

Fig. 8 - Detection thresholds for noise induced building vibrations.

SUMMARY REMARKS

Considerable progress has been made in understanding the efficacy of various metrics for quantifying the noise associated with a discrete, single source noise event such as an aircraft flyover. This type of information is essential to effective noise reduction efforts and/or equitable noise certification. However, differences in response are noted between sources which are not accounted for by metrics. This suggests that better metrics or the use of existing metrics in more sophisticated models will be required for the accurate prediction of human response particularly in cases where multiple sources are encountered.

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CEC JOINT RESEARCH ON ANNOYANCE DUE TO IMPULSE NOISE: LABORATORY STUDIES

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INTRODUCTION

In their Third Environmental Research Programme for [illegible] the Commission of the European Communities initiated and, together with participating member countries, partially funded laboratory and field research on annoyance due to impulse noise. There were two principal research coordinators: C.G. Rice (United Kingdom) for the LABORATORY GROUP and R. de Jong (Netherlands) for the FIELD GROUP. The overall programme was monitored by [illegible] of the CEC, Brussels.

This paper describes the findings of the laboratory group which was made up of team leaders from the following five countries:

Bundesrepublik Deutschland. Institut für Lärmschutz, Düsseldorf. [illegible]

Denmark. Technical University of Denmark, Lyngby. [illegible]

France. Institut [illegible], Paris. [illegible]

Netherlands. Institute for Perception TNO, Soesterberg. [illegible]

United Kingdom. Institute of Sound and Vibration Research, Southampton. [illegible]

MATERIAL, METHODS AND [illegible]

The five studies described here form [illegible] Pilot Study carried out during the Second CEC Environmental [illegible] Programme (1981), the original group of four [illegible] the inclusion of a team from Torino. Definitive [illegible] prepared with ISVR devising the experimental [illegible] A, [illegible], and D, and TNO having responsibility for study E. The [illegible] identifies the studies, the designation [illegible] I-[illegible], I-Southampton, L-Lyngby, TNO-Soesterberg and T-Torino.

STUDY	TITLE	[illegible]	[illegible]
A	NORMALISATION	ALL	[illegible]4
B	Sounds in ISOLATION	DIIT	[illegible]
C	Sounds in COMBINATION	DIL	144
D	REPLICATION-Isolation	T	4[illegible]
E	INTERACTION-Combination	TNO	[illegible]4

Normally-hearing (< 15 dB re ISO [illegible], 0.[illegible] kHz) male and female subjects (distribution [illegible] either way) between [illegible] years of age listened one at a time in a simulated domestic living room [illegible] to noises which were replayed through suitably calibrated loudspeakers. The initial noise levels in each listening facility were less than [illegible] dB(A), and the impulse noises ($L_{AI} - L_{Ae} \geq 4$ dB), either singly or in combination with traffic noise, were presented over five minute periods at levels of 35, 42, 49 or 56 dB L_{Aeq}. Throughout each presentation, subjects either sat quietly or were allowed to read before filling out a response questionnaire at the end of the period. The presentation orders of noises were based on balanced Latin Squares which required 1[illegible] or 24 subjects, depending upon the study in question; subjects listened to every noise treatment within a particular design.

STUDY A

The purpose of this normalisation study was to extend to lower levels two of the noises used in the CEC Pilot Study (1981), in order to see if teams could obtain results which were not only consistent with each other, but also formed a logical extrapolation of the earlier findings. Every subject who took part in Study A also participated in one of the other Studies B to E. Eight treatments were used - synthetic gunfire ([illegible]) and road traffic (T1) noises being presented at the four levels. At the end of each listening period the following questions were asked:

A1 How annoying would you find the noise you have just heard, if you heard it all the time?

NOT ANNOYING AT ALL 0 1 2 3 4 5 6 7 8 9 EXTREMELY ANNOYING

A2 How annoying would you find this noise if you heard it all the time in your own living room in the evening?

NOT ANNOYING AT ALL 0 1 2 3 4 5 6 7 8 9 EXTREMELY ANNOYING

A3 Would you say you would be very much annoyed or not by the noise if you heard it all the time in your own living room in the evening?

Yes .... No ....

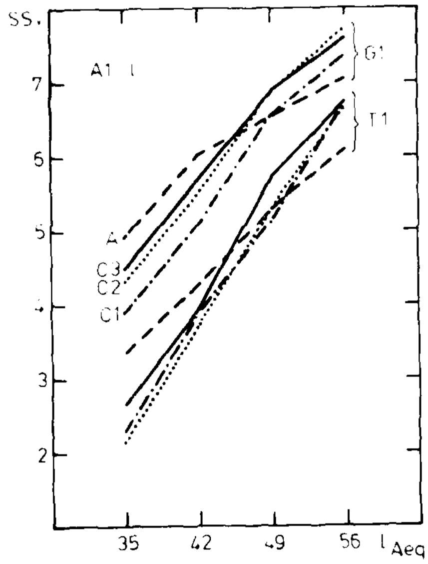

Figure 1 - Study A:
Subject group effects

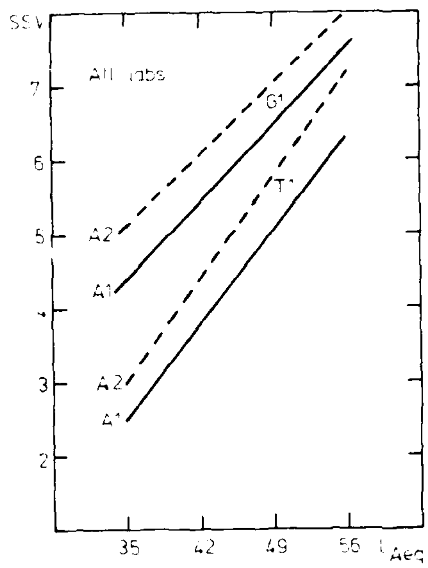

Figure 2 - Study A:
Question effect

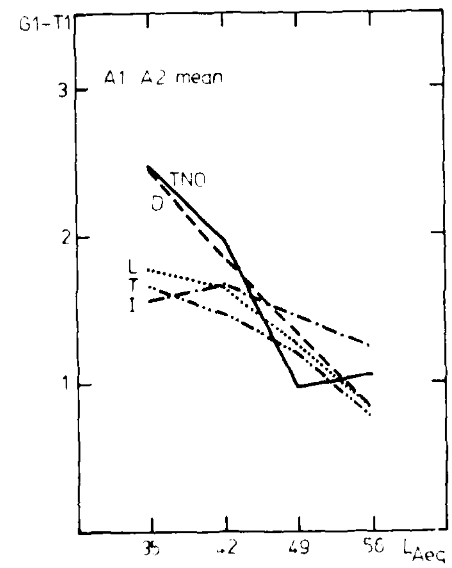

Figure 3 - Study A:
Interaction effect

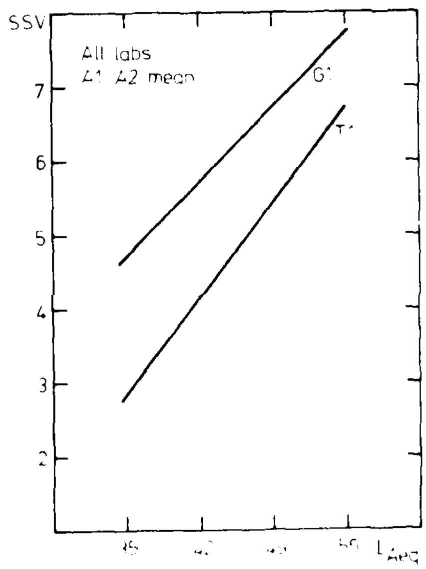

Figure 4 - Study A:
Model estimate

Figure 1 shows the results obtained by Lyngby for responses to question A1. Four sets of normalisation data were obtained from the 4 [illegible] subjects who also participated in studies B and C. Whilst there are absolute subjective scale value (SSV) differences between the sets of data, the relative patterns are not significantly different. Similar results were obtained for questions A2 and by the other teams. The pooled data for A1 and A2 are shown in Figure 2, where the noise - level interaction is distinctly more significant for the home projection question A2. This interaction represents the different rates of growth of annoyance of the two noises, the relative magnitudes of which differ slightly between teams as shown in Figure 3. The best total pooled estimate of the relative judged annoyance of gunfire and traffic noise is shown in Figure 4, where the interaction is approaching significance.

STUDY B

Each team participating in this study used four noises presented in isolation. Two of the noises were common, synthetic gunfire (G1) and a new series of traffic recordings (T2) made at four different distances from a busy highway in order to maintain character changes with level. Teams were free to choose the remaining two noises of their set: [illegible] life military and civil firing range situations (G_R, G_M, G_C) and [illegible]tion impulsive (C, P) noises being selected.

No significant differences were found between the relative [illegible] annoyance of sounds common to each team. The pooled data is shown in Figure 5, where it may be seen that G_R, G1 and P are significantly more annoying than traffic noise, with G_M, G_C & C [illegible]. This infers that all impulse noises are not necessarily equally annoying, the character differences obviously playing some part. [illegible], however, impulse noise is significantly more annoying than traffic noise, the results in Figure 6 resembling the Study A data given in Figure 4. The changing character of the T2 traffic noise does not appear to manifest itself in a markedly different dose-response relationship from that produced by the T1 noise, whose level changes were achieved by amplitude [illegible].

PERCENTILE RESPONSES

The percentage of respondents admitting to being [illegible] annoyed varies considerably depending upon the way in which the question is asked. For example, the direct question A3 elicits far higher percentages [illegible] than does a retrospective calibration of individual data. This latter information was obtained by asking subjects, at the completion of their listening sessions, to indicate in a question B1 at which point on the [illegible] 9 scale they felt they would be [illegible] annoyed. Scoring each individual response to the A2 questions [illegible] depending upon whether the descriptor in question was less than (or equal to or greater than) the number indicated, allowed the data in Figures [illegible] and 8 to be obtained.

Although the gunfire-traffic differential is still clearly maintained, it may be seen that the closest approximation to the synthesis of field data advocated by Schultz (1978), corrected to indoor L_{Aeq} [illegible] by the numerical subtraction of 17 dB, is obtained using the retrospective calibration approach.

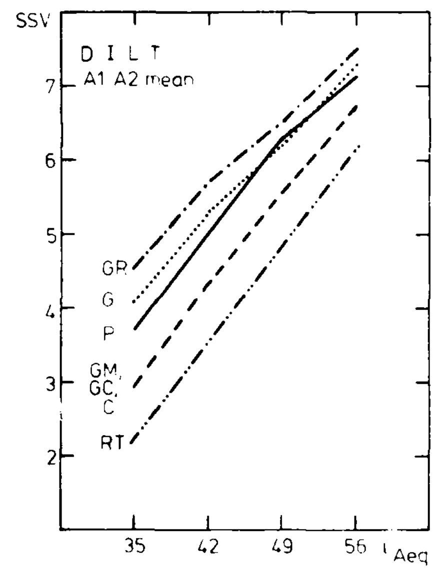

Figure 5 - Study B:
Sound effects

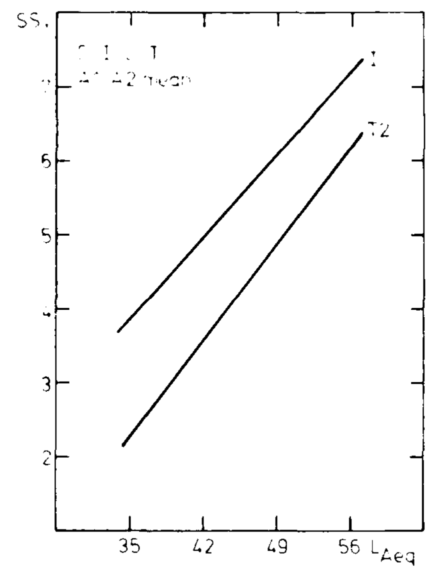

Figure 6 - Study B
Pooled estimate

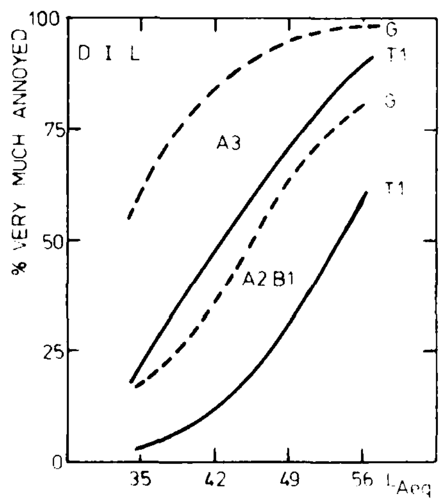

Figure 7 - Study A:
Percentile responses

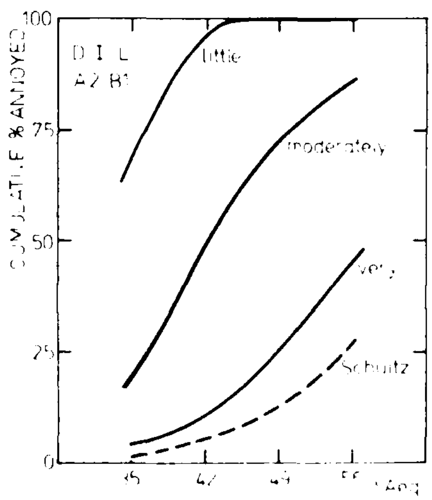

Figure 8 - Study B:
Traffic responses

IMPULSE NOISE CORRECTION

One of the main reasons for carrying out the present series of studies was to investigate the nature and magnitude of the correction necessary to be applied to impulse noise in order to account for the increased annoyance that it evokes. The long-established practice mentioned in ISO/R 1996-1971 has been to penalise such noise by adding 5 dB to its measured level. Extrapolation of the pilot study data, however, indicated that the correction may vary between [illegible] and [illegible] dB, depending upon noise level.

Figure [illegible] shows the pooled data for [illegible] ([illegible]) and traffic (T) [illegible] obtained by those teams (Düsseldorf, ISVR and Lyngby) who [illegible] comparable designs in the pilot and main studies. Most [illegible] is the range effect; that is the way in which subjects adapt their [illegible] scale value (SSV) responses to fit the noise set, rather than use the scale in an absolute sense. Some caution is needed when normalising these two sets of data because at first glance it appears that the noise × level interaction obtained in the main study may in fact be significant. Figure 10 illustrates this point and leads to the impulse noise correction shown in Figure 11; that is 0 dB at an L_{Aeq} of 67 dB rising to 10 dB as the L_{Aeq} falls to 35 dB. However, if the pooled data for all impulse (I) noises from all the studies are included, the interaction is not significant at lower noise levels and the dose-response relationships become less divergent. The impulse noise correction is then reduced and steadies at a maximum value of about 8 dB.

At the commonly occurring outdoor community noise levels of about 50-70 dB L_{Aeq}, the impulse noise correction may need to be slightly higher than 5 dB. At levels higher than 70 dB the usefulness of any correction is less certain. The ISO recommendation of a single valued impulse noise correction of 5 dB is not that unreasonable, even though it does not tell the whole story.

STUDY D

The importance of replication was investigated by Torino. In Study A, 24 rather than 16 subjects were used who replicated their judgements on one subsequent occasion. No significant effect of replication was found, and as already inferred in the discussion of Study A, the noise × level interaction was only significant for question A2. A similar procedure was followed for Study B, where again no effect of replication was found. The noise × level interaction effects were also not significant. The correlation coefficient of the test-retest SSV scores of subjects averaged over questions A1-A2 and Studies A-B was about 0.8. Hence, up to [illegible] of the variance may be due to uncertainty in subjects' responses.

The only trends noticeable from the results of this study were that subjects appeared to make slightly wider use of the subjective scale than did those from other teams. Furthermore, the replication tended to heighten this effect, making the regression lines somewhat steeper. The differential effects of the noises with respect to each other were not noticeably different from the results obtained by some of the other teams. No particular benefit could be attributed to the use of 24 rather than 16 subjects.

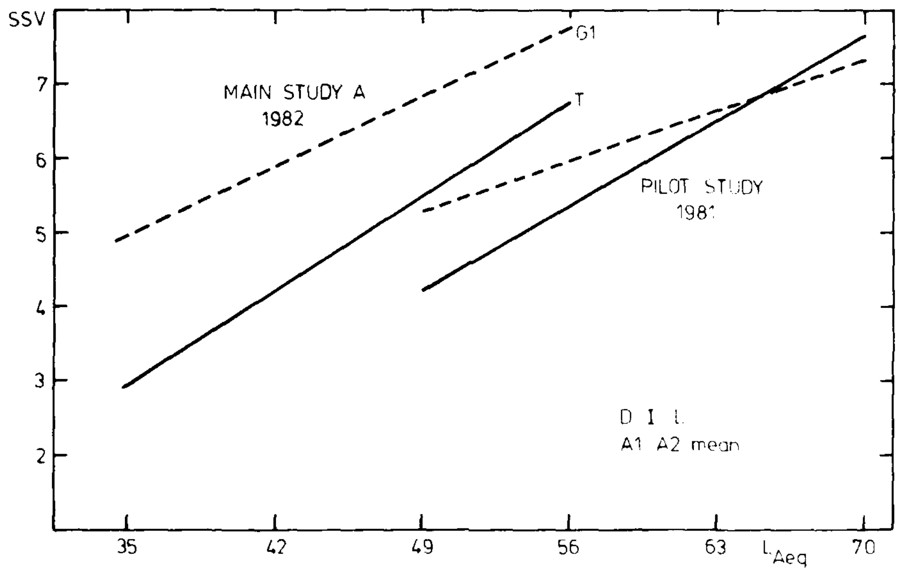

Figure 9 - Comparison of main and pilot studies

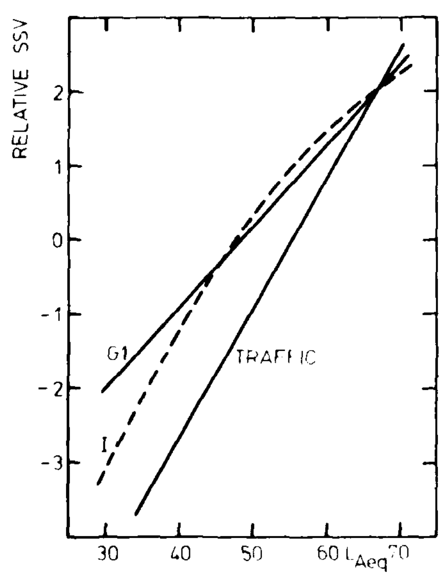

Figure 10 - Normalised data

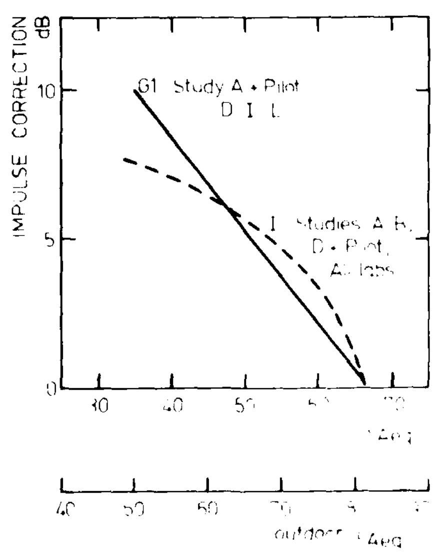

Figure 11 - Impulse corrections

STUDY C

In real life, sounds are seldom heard in isolation, and it was considered vital that some consideration be given to the way in which subjects respond to combinations of impulse and traffic noises. The standard gunfire (G1) noise was presented in combination with either a high ([illegible] L_{Aeq}) or low (35 L_{Aeq}) traffic background (T3) noise. The traffic noise could either be held constant over the whole period during which each of the five minute gunfire levels were presented, or it could be changed each time the impulse noise level was varied. Düsseldorf used the constant approach; ISVR and Lyngby the varied approach; no significant difference was found between these approaches, although the constant background presentation is marginally preferred.

The study was sub-divided into three parts (C1, C2 and C3), the only difference being in the questions asked of the 3 × 16 subjects. In Study C1, subjects were asked to judge *total* noise only (Qn. C3.1), in C2 *impulse* noise only (Qn. C3.2) and in C3, *total*, *impulse* and *traffic* noise (Qns. C3.1-3). The reason for these differences was to investigate the role of the following questions in the formulation of dose-response relationships.

C3.1 How annoying would you find the *total* noise you have just heard, if you heard it all the time in your own living room in the evening?

NOT AT ALL ANNOYING 0 1 2 3 4 5 6 7 8 9 EXTREMELY ANNOYING

C3.2 How annoying would you find the *impulse* noise you have just heard, if you heard it all the time in your own living room in the evening?

NOT AT ALL ANNOYING 0 1 2 3 4 5 6 7 8 9 EXTREMELY ANNOYING

C3.3 How annoying would you find the *traffic* noise you have just heard, if you heard it all the time in your own living room in the evening?

NOT AT ALL ANNOYING 0 1 2 3 4 5 6 7 8 9 EXTREMELY ANNOYING

There is no doubt that for sounds heard in combination the annoyance responses are confounded by the way in which the question is asked, as well as by the relative levels of the noises in question. In Study C3 in the low background situation, Figure 12 shows that *impulse or source specific* annoyance is surprisingly greater than *total* annoyance, whereas in a high background *total* annoyance appears in Figure 13 to be the subjectively perceived sum of the separate source contributions. Furthermore, *total* annoyance does not appear to correlate uniquely with total L_{Aeq}, which means that background noise level needs to be specified as a separate parameter. This result, also confirmed by the results of studies C1 and E, is demonstrated in Figures 14 and 15. *Source-specific* annoyance to impulse noise is either heightened or depressed, depending upon whether it is heard in a low or high background, and this effect is clearly demonstrated in Figure 16.

If subjects are asked to rate only *total* (Study C1) or *impulse* (Study C2) annoyance, the relationships shown in Figure 17 are obtained. Here it may be seen that there is no difference between *total* or *impulse* noise annoyance in the low background situation where the impulse noise dominates, and subjects do not have to answer contrasting questions. The responses

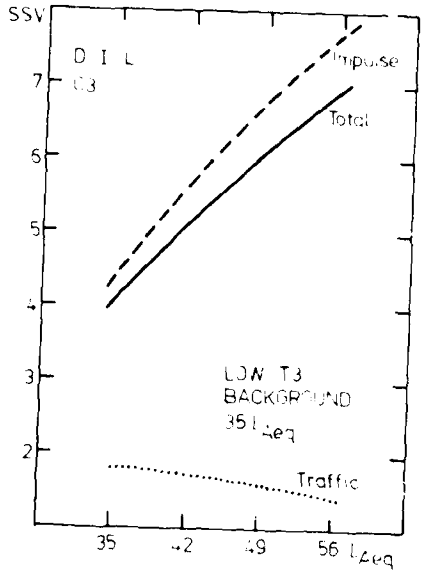

Figure 12 - Study C3:
Annoyance responses

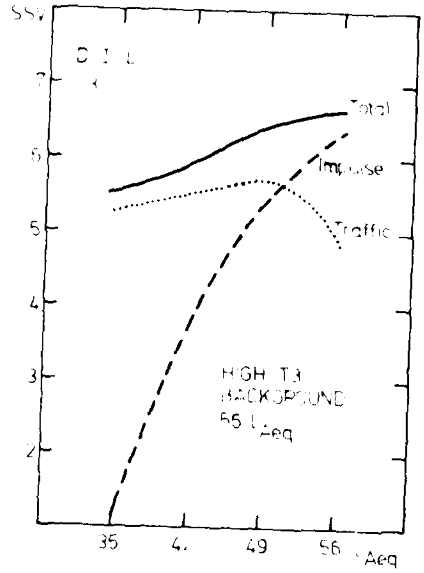

Figure 13 - Study C3:
Annoyance responses

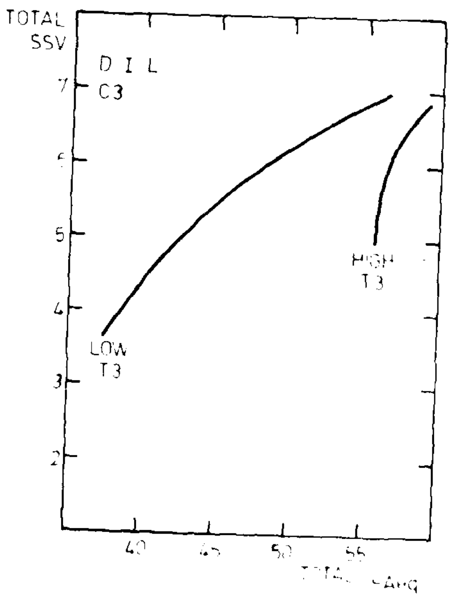

Figure 14 - Study C3:
Total annoyance

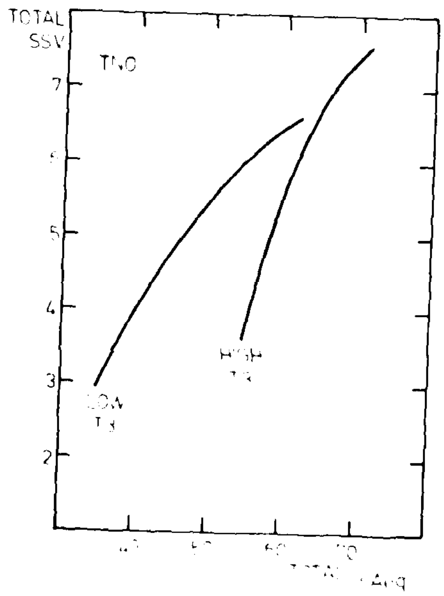

Figure 15 - Study E:
Total annoyance

in the high background are relatively similar to those obtained in Study C3 (see Figure 13), although the shape of the dose-response relationships is different. *Source-specific* annoyance to impulse noise was also shown to be more annoying when heard in low backgrounds rather than high, a finding that is consistently obtained regardless of how the question was asked.

STUDY E

This study was designed and carried out by TNO in order to investigate the effects which certain interactions had on judgements of combinations of noises. The following aspects were studied: *instruction* (source-specific or total annoyance); *background noise* (35 and 55 dB, L_{Aeq}); *signal to noise ratio* (-15 to +25 dB) and *signal type* (traffic, gunfire and construction noise). Four separate groups of 16 subjects heard each of the signal types in either a low or high background of traffic noise. Any one group of subjects only used one instruction and listened to the signal types in the presence of only one background noise condition. Subject groups were therefore confounded by some of the aspects studied.

While the results in Figure 15 seem to confirm that *total* annoyance is not uniquely correlated with total L_{Aeq}, they also demonstrate a *range effect*. This effect is particularly noticeable in the results shown in Figures 18 and 19, where each group of subjects appears to have used the response scales in a similar fashion. That is, they fitted subjective scale values to the noise sets using the numbers in a relative rather than an absolute sense. It may be fortuitous therefore that the results in Figures 15 and 18 show the same effects as the Düsseldorf, ISVR and Lyngby data in Figures 14 and 16, respectively. Certainly the results of Figure 19 conflict with those of Study C. It is unlikely that *total* annoyance in a low background is always higher than that manifested by the same noises heard in a high background. This study clearly highlights once more the influences which both experimental design and the different ways in which annoyance response data may be elicited, can have on the interpretation of human response data.

INTERPRETATION OF COMBINED NOISE DATA

The results of Studies C and E should seriously call into doubt the ways in which annoyance response data are obtained. Particularly important is the difference between a repeated measures laboratory experiment (Study C), which represents a dynamic situation in which subjects listen to all conditions and accumulate wide experience, and the single exposure experience or static situation encountered in social surveys. Study E was intermediate of these two extremes, and stresses the added care which researchers need to take when designing and interpreting the results of social surveys and laboratory studies.

However, despite these caut´ nary statements, certain facts clearly emerge from the studies describe here. Impulse noises heard in isolation require a level dependent correction of the order 5-10 dB over the outdoor range of 35-56 dB L_{Aeq} in order to take account of the increased annoyance likely to be elicited.

For noises heard in combination, the position is not so straightforward. Although impulse noise is more annoying in a low than a high background of traffic noise, *total* annoyance of the combined situation is

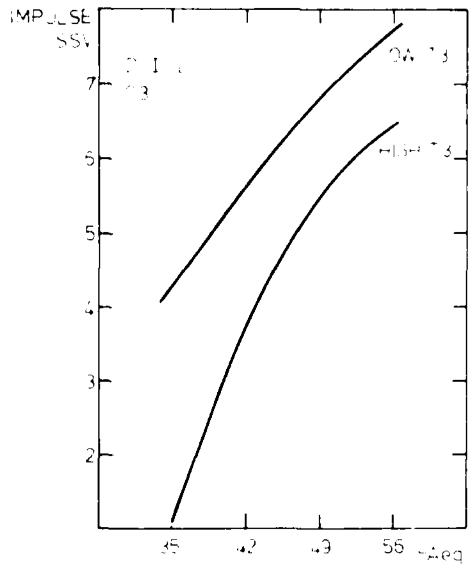

Figure 16 - Study C3:
Impulse annoyance

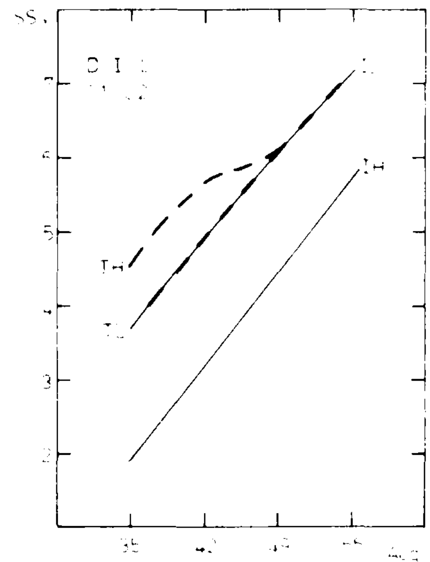

Figure [illegible] - Studies [illegible] and [illegible]:
Annoyance responses

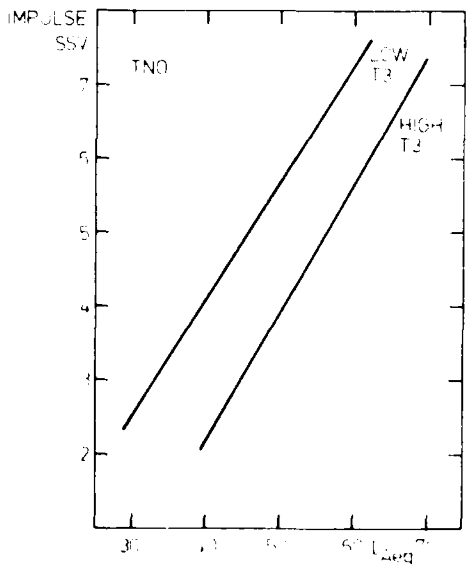

Figure [illegible] - Study E:
Impulse annoyance

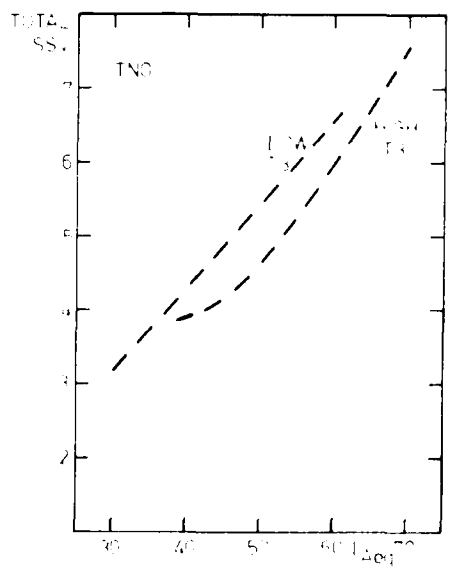

Figure [illegible] - Study F:
Annoyance responses

greatest in the high background situation. This infers that both *total* and *source-specific* annoyance judgements should be used, particularly as there is evidence to suggest that subjects may over-react to *source-specific* questions. If such modelling can be generalised, this finding has implications in other situations, for example aircraft noise, where the importance of background noise is a topical issue. In this case one would hypothesize that although *source-specific* annoyance of aircraft noise might be greatest in low noise backgrounds, *total* annoyance would be greatest in the high background areas. Therefore the high background situation is the more environmentally disadvantageous, and planning decisions should be made on the basis of *total* as well as *source-specific* reactions. If this were implemented the thought that people exposed to aircraft noise in quiet areas suffer greater annoyance than those in noisy areas should be dispelled.

CONCLUSIONS

(1) Impulse noises heard in isolation require a level dependent correction which varies 0 to 10 dB over the range 70 to 35 dB L_{Aeq}.

(2) Responses to combinations of impulse and traffic noise are influenced by the way in which the annoyance questions are asked.

(3) *Source-specific* annoyance to impulse noise increases as background noise decreases.

(4) *Total* annoyance to combinations of noise appears to be the subjectively perceived sum of the separate source contributions.

(5) *Total* annoyance does not uniquely correlate with total L_{Aeq}; it is also a function of background noise level.

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ACKNOWLEDGEMENTS

I wish to thank the team leaders of the participating countries in both Laboratory and Field Groups, and their colleagues for the cooperation and support given throughout the duration of this research programme. Acknowledgement is also made of the experimental design and statistical analysis assistance given by Dr. J.A. John of the Department of Mathematics, University of Southampton. The work carried out in each country was partially funded by the Commission of the European Communities.

C.E.C. JOINT RESEARCH ON ANNOYANCE DUE TO IMPULSE NOISE: FIELD STUDIES.

Jong, Ronald G. de, and D. Commins

TNO Research Institute for Environmental Hygiene, Delft, The Netherlands

INTRODUCTION

In their Third Environmental Research Programme for 1982/1983 the Commission of the European Communities initiated and, together with participating member countries, partially funded laboratory and field studies on annoyance due to impulsive sounds.

This paper describes the findings of the field group which was made up of the teams from the following four countries:

Federal Republic of Germany.
Medizinisches Institut für Umwelthygiene,
Düsseldorf.
(J.Kastka, U. Ritterstaedt)

France.
Société d'Etudes pour le Développement Economique et Social,
Paris.
(J.M. Rabrait)

Ireland.
Institute for Industrial Research and Standards.
Economic and Social Research Institute,
Dublin.
(B. Hayden, B. Whelan)

The Netherlands.
TNO Research Institute for Environmental Hygiene,
Delft.
(R.G. de Jong, Y. Groeneveld, R. v.d. Berg)

HISTORY OF THE PROJECT

In their Second Environmental Research Programme for 1980/81 the Commission of the European Communities initiated a new line of research. This was the line investigating the effects of impulse noise on human beings. In this period a pilot study was carried out which eventually led to the current field study. The participants in the pilot study came from France, Ireland, the United Kingdom and the Netherlands. The aim of the pilot study was to get an idea of the prevalence of impulse noises. Without going into detail the results of this pilot study have led to the current study, which aims at investigating whether reliable dose-effect relationships for more of less stationary impulse noise sources can be established.
In the pilot study a common questionnaire has been developed. This involved a lot of "trouble shooting" in the sense that the researchers had to develop routines to overcome difficulties of language and culture, difficulties of working together in an international setting,communicating over long distances.
This questionnaire formed the framework for the one used in the current study. Of course not exactly the same questionnaire could be used because the aim of the study had changed.

DESIGN OF THE STUDY

In organizing the main study many of the experiences from the pilot study were used.
To mention a few of those experiences:

- the very loose organizational matrix of the pilot stage was abandoned. One coordinator was appointed. Tasks were divided according to the individual expertise in the group and meetings were scheduled about each two months.
- the translation of the questionnaire was monitored closely. After completion of the questionnaire in English, it was translated into French, German and Dutch by experts and translated back into English by other experts, to make sure the translation had been adequate.
  In the questionnaire possibilities for comparison with the laberatory study on some questions were built in.
- an uniform sampling strategy has been developed. Some preliminary noise measurements, unknown to the residents in the area, were carried out prior to the social survey. The purpose of this was to determine whether a given area, subject to impulse noise, was suitable for the project.
  An [illegible] reference point was chosen in that section of the area which was [illegible] exposed to the impulse noise.
  Then, zones were defined within the area in terms of the levels generated by the impulse noise source.
  The zoning criteria were as follows:
  - the reference zone, that is the most exposed zone in the area, was to have an impulse noise to background noise ratio of at least 10 dB(A);
  - a difference of at least 5 dB(A) for the impulse noise levels was required between zones.

  In addition each area had to be able to provide two or three zones where a sufficient number of interviews could be conducted.

Within each zone respondents were selected in a way that made the sample representative for the population at risk in this zone.

The population at risk was defined as "people who are at home at least three days a week when the impulse noise source is in operation, and who are 18 years or older".

- a code book for the common coding of the social survey data was developed.
- computer programmes were developed to ensure that each team processed its data in the same way.
  A problem occured here in, that each team had different computer equipment. Each computer needs its own parameters to be able to read a tape. But it is not merely a matter of communicating to the other groups what parameters to use. The problem is that a certain parameter may have another meaning for one computer than for the other. So it is matter of searching after the meaning a parameter has in the various systems.

Working together to overcome the difficulties encountered in this joint study - which proved to be many and sometimes rather basic to the succesfull completion of a project where many experts are involved (all with their own attitudes, habits, routines and preferences) - make this study unique in that the same study was in fact carried out in different countries instead of four separate studies on a similar topic.

SURVEY

The field work of the social survey was carried out between September 1982 and April 1983. In each country about 400 people were questioned, adding up to a total of 1627 respondents.

The questionnaire which took about 30 minutes, consists in broad outline of four parts:

- about the house and the environment in general;
- about noise in general;
- about the specific noise sources we are interested in (impulse and traffic);
- a classification section in which age, sex, education, number of people in the household and such-like items are dealt with.

In designing the study it has been taken care of that two noise sources are common to all teams:

- noise from shooting ranges;
- traffic noise as the dominating aspect of the background noise.

These two common sources act, as it were, as the "anchors" against which to evaluate the other sources which are scrapyards, dockyards and other metal working industries, a dairy, a building site and a shunting yard.

After the interviews had been completed a noise monitoring campaign was conducted at each site over several days.

Two types of data acquisition were performed:

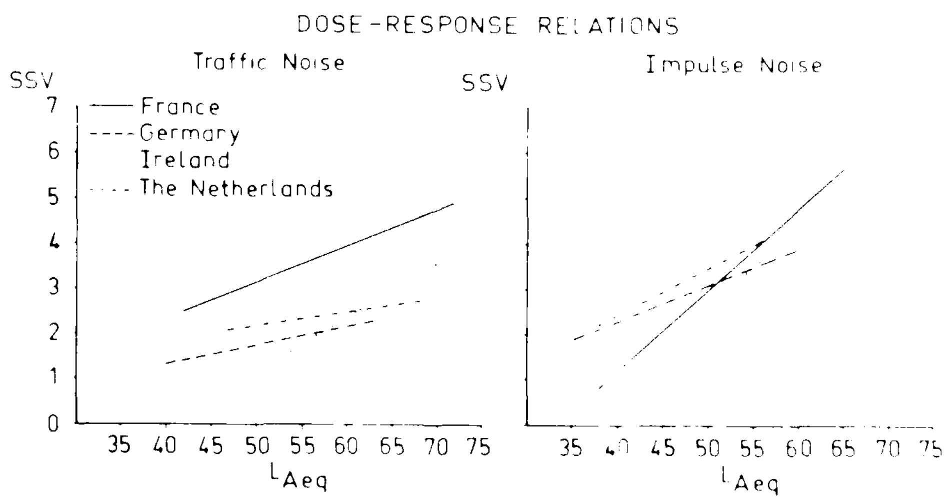
First: noise monitoring at the area reference point. The purpose of these measurements was to characterize the pattern and the variation of the levels of the impulse noise source over three 24-hour periods: during the first period by the acquisition of series of A-weighted equivalent noise levels over one minute and during the second and third period by the acquisition every hour of L_{Aeq}, L_{A1}, L_{A5}, L_{A10}, L_{A50}, L_{A90}, L_{A95}, L_{A99}.

Second: by making simultaneous analog recordings during the first period, both at the Area Reference Point, the Zone Reference Point and the Zone Secondary Point.

The aim of the recording at the Area Reference Point, which is the measuring point of the most exposed zone in the area, is to ensure a cross check and to record information about the nature of the impulse noise source as well as about the character of the background noise. The recordings at the Zone Reference Points (defined as the measuring points, representative for the zones in question) are carried out to establish the relationship between the zones with respect to the impulse noise. The recordings at the Zone Secondary Points are intended as a check of the homogeneity of each zone.
At the moment noise measurements have not yet been completed. This is due to the bad weather encountered last winter and early spring, which have made it impossible most of the time to carry out the noise measurements within the meteorological boundaries requested.
This of course means that we are not able to present the final results at this moment.
It will be clear that from the noise data many noise measures can be derived. For this paper we will confine ourselves to a simple measure: the equivalent noise level over the time in which the impulse noise source is in operation. That means regular working hours for that particular source.

RESULTS

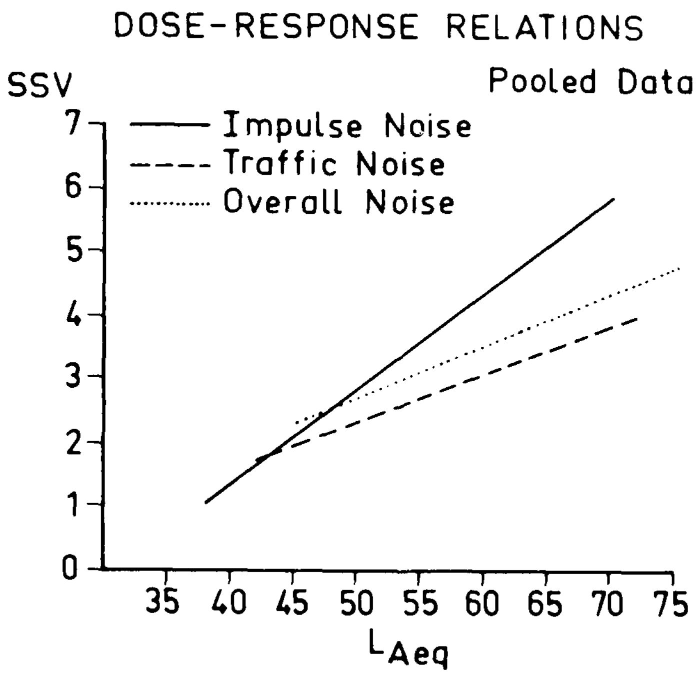
Now some of the preliminary results will be presented.



In this figure the regression equations for traffic noise and for impulse noise are presented together. On the horizontal axis the equivalent noise level in dB(A) is presented, and on the vertical axis the same ten-point annoyance scale used in the laboratory studies (SSV = Subjective Scale

Value) [1]. The results about the impulse noise fit in beautifully with each other. As far as traffic noise is concerned the French results seem to be deviant, and further analysis will be necessary to find out what causes this deviancy.

In figure 2 the pooled data are shown. From about 45 dB on the impulse noise appears to be more annoying than traffic noise. Moreover, as the regression lines are not parallel one might be inclined to infer that the difference in annoyance is level dependant, and is so just the other way around as found in the laboratory studies [1]: the higher the noise level, the greater the difference. This is an interesting observation and it seems worthwile to dig somewhat deeper.



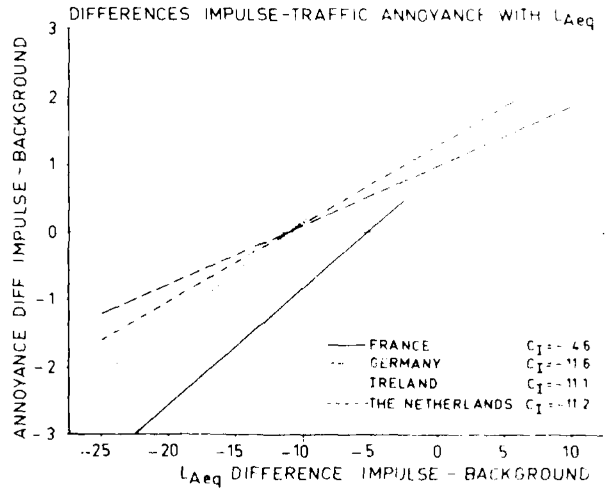
The approach up to now is a rather crude approach. Using the regression lines comparisons are made across people, and not within people. People who are exposed to, for instance, 65 dB(A) from an impulse noise source

are not necessarily the same people who are exposed to a traffic noise level of 65 dB(A). In this case we have the opportunity to compare within people to see how they rate the annoyance caused by impulse noise against the annoyance caused by the background noise, in our case traffic noise. This provides us with a more sophisticated tool to compare the annoyance with the aim to establish the size of the penalty - if any - for impulse noise compared with more continuous noise.

For the same person differences in L_{Aeq} were related to differences in annoyance scores.

The cutting point of the emerging regression line with the X-axis is -8,9. This differs significantly from the -5 of the ISO R1996 (1971) [2].

The regression lines for each country on its own show a remarkably good resemblance for the German, Irish and Dutch data, while the French data are deviating as figure 3 shows. This will be due to the traffic noise data presented earlier (figure 1). The good resemblance of the German, Irish and Dutch data could even point to a greater impulse correction than the -8,9 from the pooled data.

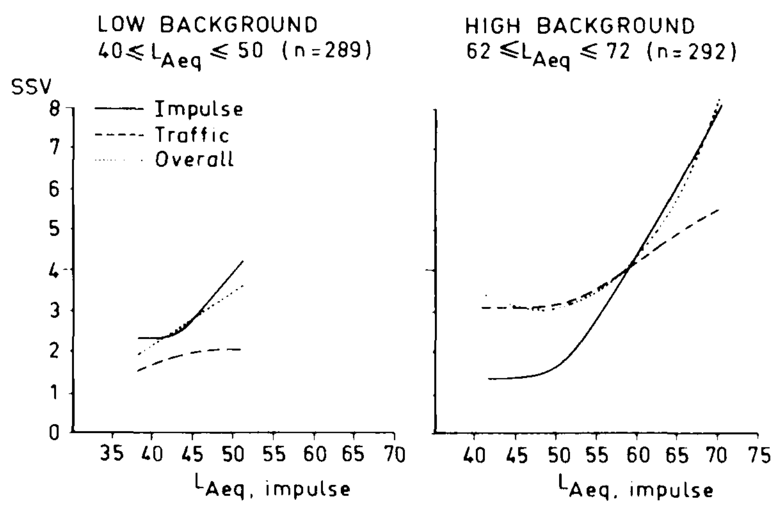


Now we come to the question of level dependency.

Sites with relatively high background noise levels were seperated from those with relatively low background noise levels. No significant difference was found: the level dependency, demonstrated in the laboratory experiments, can not be confirmed from these field data, though a tendency can be shown.

Another interesting topic is to see how the annoyance caused by the total noise situation relates to the annoyance caused by the impulse noise and traffic noise.

Is the overall annoyance, as an attitudinal concept, formed on the basis of an additive model after the approach of Rokeach, Fishbein [e.g. 3] and others, or does the averaging process of the classical attitude theories [e.g. 4] play a part?



Zones were selected with a low and with a high background noise. Impulse, traffic and overall annoyance within the same individuals were plotted

against the equivalent noise level of the impulse noise (see fig. 4). The left side of the figure shows the low background noise condition. The overall annoyance fairly well follows the impulse noise annoyance, which is the psychologically dominant one in this situation, though the noise range incidentally is about the same for impulse and traffic noise. The right part of the figure shows that the overall annoyance very closely follows the psychologically dominant noise, which is traffic noise up to about 58 dB(A) and impulse noise above that level. As the average background noise level in this condition is about 67 dB(A), again the impulse correction of about 9 dB is found. Looking at the impulse noise curves, again the tendency is seen for impulse noise to be more annoying in the low background condition.
From the observation that the overall annoyance very closely follows the annoyance caused by the psychologically dominant noise neither the additive nor the averaging models can be supported.

CONCLUSIONS

To conclude with we can state:

First: the 5 dB penalty for impulse noise as recommended by the ISO seems a little bit to conservative looking at both the results from the laboratory studies presented by Rice [1] and the results from the field study, though one has to be careful because not all data are available yet, so this is a preliminary conclusion.

Second: though one has to be careful - at this point - to subscribe the findings of the laboratory study about the level dependency, together with the findings of how the overall annoyance relates to the psychologically dominant noise on a site, the importance of the role of the background noise in studying noise annoyance in a field survey is beyond doubt.

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COMPARISON OF NOISINESS FUNCTIONS FROM DIFFERENT NOISE SOURCES METHODOLOGICAL PROBLEMS AND SUBSTANTIVE RESULTS

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1: INTRODUCTION.

Environmental noise sources like road traffic, aircrafts, railway lines, factories, construction sites etc. seem to be differently 'noisy' and annoying for exposed residents. But what is the magnitude of such differences? For a quantification two perspectives are possible:

(1) How large is the difference in annoyance in case of equal noise exposure?

(2) How large is the difference in noise exposure which causes equal annoyance?

The first question reflects the social-scientific view. The second question is fundamental if 'noisiness' differences shall be applicated in noise regulations or laws, e.g., immission limits in residential areas.

Since 'stimulus' indices and 'reaction' variables correlate only moderately, results on (1) and (2) are not directly convertable. Furtheron it is more or less impossible to find areas with equal noise exposure or equal annoyance impacts with respect to all relevant parameters. Thus a statistical solution has to be found for convergent answers on both questions. Two steps are necessary:

- Defining a 'noisiness function' which reflects the relationship between acoustical stimulus (exposure, noise) and reaction (behavioral effects, annoyance) for each relevant noise source;
- Quantifying noisiness differences by comparing noisiness functions in psychological and acoustical terms.

(Terminological note: The term "noisiness function" shall denote any function which relates both noise exposure to noise effects and noise effects to noise exposure).

Some of the resulting methodological problems shall be treated here (for a more detailled discussion see ROHRMANN, 1983; cf. also FIELDS & WALKER, 1980; SCHULTZ, 1980).

2: DEFINING NOISINESS FUNCTIONS FOR NOISE SOURCES.

In a usual noise annoyance survey, individual data on behavior in response to noise (B) are gathered with respect to selected acoustical stimulus levels (A). This enables a scattergram of A and B, and the contingency can be measured by a correlation coefficient (common results range from r_{AB} = .30 to .60). If the degree of annoyance caused by a noise level shall be expressed in a general 'noisiness function', several decisions are required:

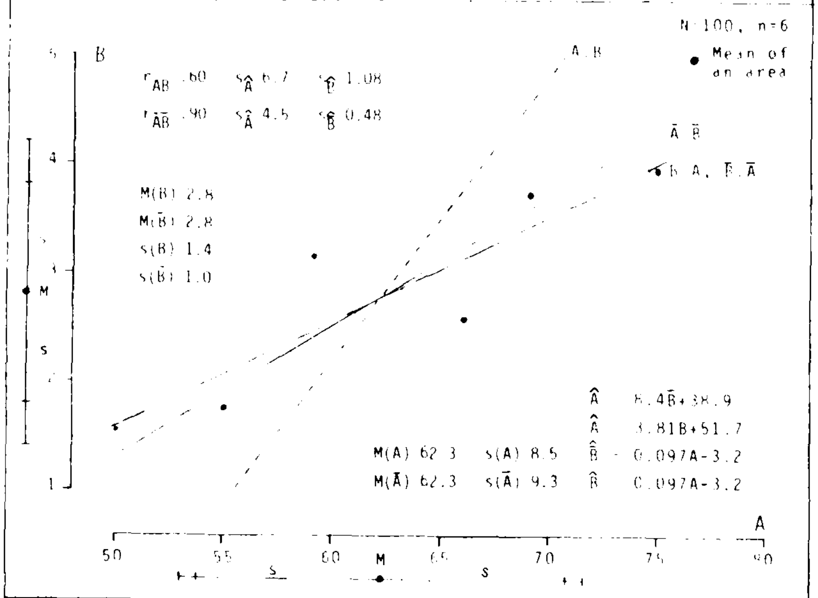
(1) Individual or mean reaction data (B, $\bar{B}$)?
A fictive data set shown in Box 1 may illustrate the problem. In this case (100 respondents in 6 areas) the correlation is 0.6 on the individual basis (r_{AB}) but 0.9 if the means of A and B per area are used ($r_{\bar{A}\bar{B}}$, n=6, grouped or collective data). For the present purpose of noisiness comparisons it seems appropriate to use mean reactions because usually no individual noise data are available, aggregated noisiness functions are more stable and the point of view here is mainly 'ecological'.

(2) Linear or non-linear A-B-function?
Theoretically a S-shaped function is to be expected for the relationship of A and B. Yet the inspection of empirical data shows that in the relevant range between L_m = 50 and 75 dB(A) a linear function is quite appropriate, at least if means on reaction scales are used (and not dichotomies like "% highly annoyed"). Additionally linear solutions have statistical advantages.

(3) Fitting of functions according to deviations in A or in B?
Usually a 'conventional' regression approach is made, namely predicting B by A (according to the cause-effect relation). But in the mentioned

Box 1

TEST DATA "X-NOISE": REGRESSIONS A ON B AND B ON A (IND./COLL.DATA)



Abbr.: A = acoustical stimulus; B = behavioral reaction; $\bar{A}$, $\bar{B}$ = mean values per area; N = number of respondents; n = number of areas; M = mean; r = correlation; A.B etc. = regression lines; $\hat{A}$ etc. = estimation by regression function.

legislation context an opposite perspective is suggested. Thus two regression lines are possible, A.B and B.A, or $\bar{A}.\bar{B}$ and $\bar{B}.\bar{A}$ for mean reactions, as shown in Box 1. (Note: In this special case B.A and $\bar{B}.\bar{A}$ fall together because A is grouped).

There is no substantial justification for one of these solutions. It seems more appropriate to compute 'non-directed' A-B-functions (nAB), as done in ROHRMANN et al. (1980) or SCHOMER et al. (1981). Several approaches are possible; a fundamental rationale was given already by MADANSKY (1959), using error terms for both related variables. Given certain conditions, a simplified solution for B = mA + c is:

$$B = (s_B/s_A)A + \bar{B} - (s_B/s_A)\bar{A},$$

yielding a straight line in between the two usual regression lines (cf. ROHRMANN, 1983). The main advantage is that corresponding values in

A or B are convertable by only one function which applies equally to the relations A-B and B-A.

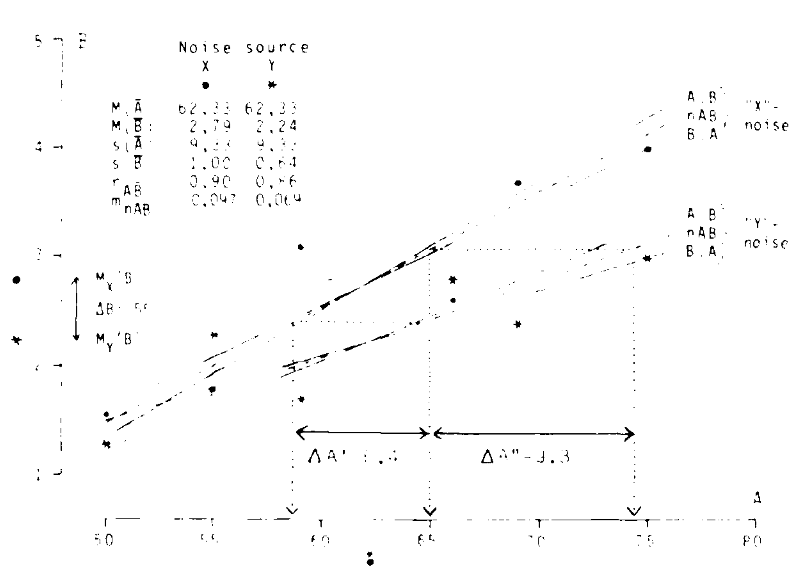
3: QUANTIFYING THE NOISINESS DIFFERENCE BETWEEN TWO SOURCES.

If the magnitude of annoyance caused by two different noise sources shall be compared and if homologous noisiness functions are defined in both cases a direct statistical comparison is possible. The difference in annoyance units B can be expressed at any acoustical level, and it can be transformed into units of the stimulus scale A. Naturally the result depends substantially on the type of noisiness function (e.g., various regression approaches like those in Box 1 or nonlinear curves).

Box 2 demonstrates the procedure, using the data of Box 1 ("X-noise") and an additional test data deck ("Y-noise"). The example refers to mean reactions and a linear non-directed A-B-function. Within such comparisons two problems arise:

Box 2

NOISINESS DIFFERENCES X-NOISE/Y-NOISE (TEST DATA "X", "Y")



Abbr.: Δ = difference; m = slope, nAB = non-directed A-B-function. Cf. also Box 1!

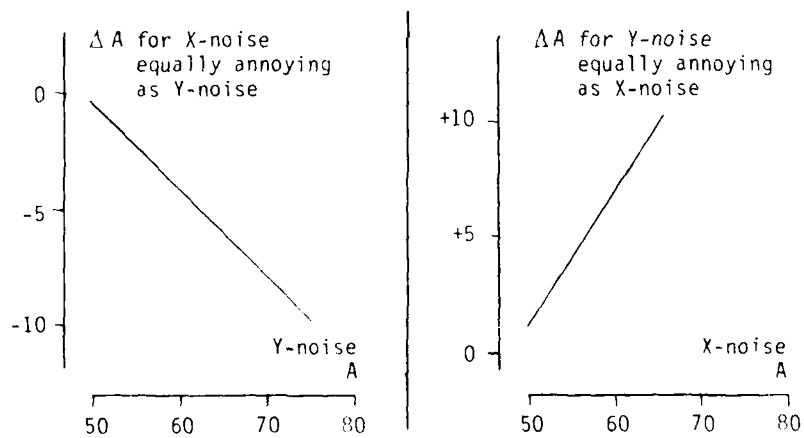
(1) Considered level of exposure.

Obviously the magnitude of noisiness differences varies between low and high exposure levels and depends on the direction of view. (In Box 2, A=65 in X-noise corresponds to A=75 in Y-noise and A=65 in Y-noise to A=59 in X-noise).
Therefore empirical findings must be specified to the considered A-level. Instead of mean results, nomograms should be given which relate noisiness differences to the respective levels of both noise sources.
Box 3 gives an example, based on the (fictive) data of Box 2. Both perspectives, X to Y and Y to X are shown.

Furtheron it should be regarded that interpolations outside the studied range of A are doubtful.

Box 3

REPRESENTATION OF NOISINESS DIFFERENCES AS NOMOGRAM



(Data according to Box 2)

(2) Processing of results pertaining to different response variables.

Whereas the acoustical stimulus may be expressed by one indicator (usually L_{eq}) noise effects consist of several distinct aspects like subjective loudness, disturbance of different activities, anger, vegetative symptoms, etc. Magnitude and even direction of noisiness differences can differ with respect to these variables.

If results shall be aggregated to reflect all relevant noise impacts, methodological as well as substantative decisions are necessary:

- Which statistical type of data shall be combined? It seems favourable first to aggregate the single variables (by a standardized mode), then to compute one noisiness function per noise source, and finally to compare them. Otherwise several differences must be averaged which may be questionable.
- Shall the variables be weighted? This may be done according to statistical criteria (e.g., sensitivity, reliability, co-variance with key indicators) or to 'anthropological' relevance of various impairments. Since differences in mean and variance already work as implicit weighting in either case an explicit decision is indicated.
- Who shall decide about weights? If available, an independent group of responsible experts is very helpful, especially in case the findings are relevant for political decisions.

Additional sensitivity analyses can explicate the influence of different procedures on the final results.

4: OVERVIEW OF EMPIRICAL RESULTS.

Recently several field studies dealt with noisiness differences of environmental noise sources. Primary investigations as well as secondary analyses were conducted. Mostly road traffic was compared with one or more additional noise types; see Box 4 for an overview. (There are several further surveys, especially those on railway versus road noise). Only few studies were explicitly designed for noisiness comparisons (an example for a somewhat sophisticated approach is SCHÜMER et al., 1981).

With respect to considerable methodological dissimilarities it is difficult to summarize the findings. The general tendency is as follows: Provided equal exposure levels, railway noise (especially from metropolitan lines) is less annoying than street traffic or aircrafts, while highway noise, construction noise and most of all industrial noise are more annoying compared to other sources. Partly such differences are larger at low, partly at high exposure levels. Expressed in terms of L_{eq}, differences up to 20 dB(A) have been ascertained.

Box 4

SUMMARY OF SOME EMPIRICAL FIELD STUDIES ON NOISINESS DIFFERENCES		

Considered types of noise sources

S = street traffic noise A = aircraft noise
H = highway noise R = railway noise
I = industrial noise C = construction noise

Study[1]	Main results concerning noisiness differences[2]	Approach[3]
FIELDS & WALKER (19[illegible]0)	S >> R; A >> R	Sec.
HEINTZ et al. (19[illegible]0)	S > R	Prim./Sec.
[illegible] et al. (1981)	A > R (Night: A >> R)	Prim.
LARGE & LUDLOW (1975)	C > S	Prim.
[illegible]	H,S ~ A >? R	Sec.
[illegible]	I >> S; H > S	Prim./Sec.
[illegible]MANN et al. (19[illegible]0)	I >> C > S ~ A >? R	Prim.

Notes:
(1) Further reports exist in addition to each of the cited studies.
(2) The considered annoyance criterion reflects general disturbance.
(3) Prim. = primary investigation; Sec. = secondary analysis.

5. DETERMINANTS OF NOISINESS DIFFERENCES.

Which factors determine whether noise from some sources are evaluated as more noisy, disturbing, bothersome, annoying, and so on? Some main influences are listed in Box 5.

Box 5

MAIN FACTORS INFLUENCING THE MAGNITUDE OF NOISINESS DIFFERENCES	
Acoustical stimulus intensity	**Acoustical moderator effects**
- Type of sound measure - Selected level of exposure	- Specific sound characteristics - Temporal structure of noise
Psychological aspects of reaction	**Psychological moderator effects**
- Considered annoyance attribute - Kind of disturbed behavior	- Associations to sound attributes - Attitudes towards noise sources

(1) Methodological points.

Obviously findings on noisiness differences depend on the acoustical index - e.g., L_{eq} or L_{peak} - and even more on the behavioral criterion - e.g., cognitive or emotional reactions, affected activities or sleep disturbance, etc. - used by the researcher. Thus the comparability of studies can be very restricted (this is especially true for indirect comparisons or secondary analyses).

(2) Moderating factors.

The substantive question is which acoustical and/or psychological factors moderate noisiness. Although empirical evidence is not yet very comprehensive, two matters seem to be important:

- the temporal relation of noisy and quiet phases (e.g., duration and/or 'intensity' of noise pauses);
- attitudinal values attributed to the source (e.g., useful, dangerous, familiar, avoidable).

Furtheron general moderators of annoyance like sensitivity to noise or health concerns have a specific effect with different kinds of noise.

6: CONCLUSIONS.

Apparently an appropriate quantification of noisiness differences requires considerable methodological efforts, and the available substantive findings are not always satisfying. Thus the basis for definite legislative decisions seems still limited.

This has some consequences for further studies:

- Above all there is a necessity for conclusive "quasi-experimental" research designs (cf. COOK & CAMPBELL, 1979). The sampling should include areas with only one single noise source as well as those with two sources (enabling intra- and interindividual comparisons); an independent variation of the levels of the included noise sources is needed; the proportion of respondents with different exposure levels must be controlled; etc.

  In Box 6 it is demonstrated which types of areas are relevant when a study for the quantification of noisiness differences is desired.

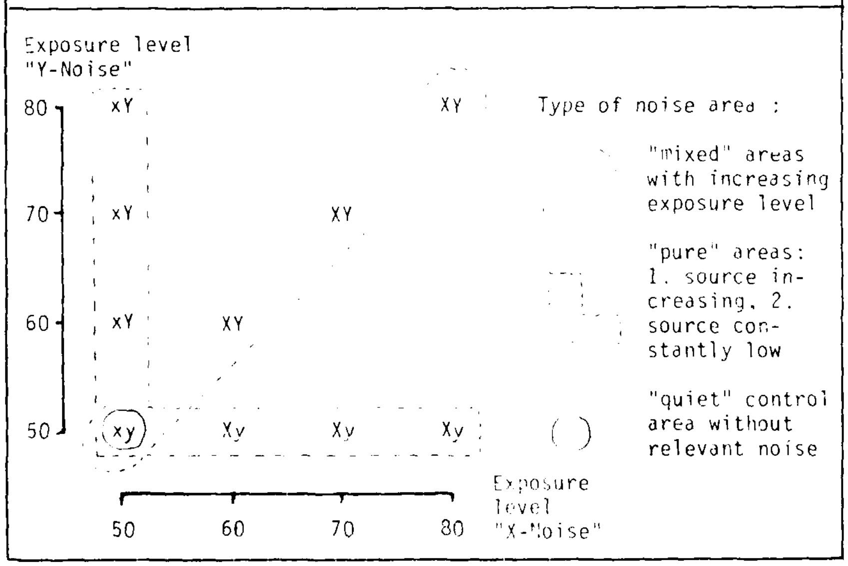
- Careful multivariate analyses are indicated to clarify the relative importance of acoustical and psychological influences on noisiness differences.

- *Any decision about variables and statistical procedures - especially any averaging, aggregating, weighting, etc.* - should be documented and explained.

Finally, an intensified international cooperation may facilitate such intentions.

Box 6

TYPES OF NOISE CONDITIONS RELEVANT FOR NOISINESS COMPARISONS



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RELIABILITY AND VALIDITY OF REACTION VARIABLES IN COMMUNITY NOISE RESEARCH.

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INTRODUCTION

The motivation behind [illegible] to formulate and quantify the "dose-response" relationship between the [illegible] noise to which an individual is exposed and the extent of [illegible] reaction to the noise. Because of th[illegible] variables used to measure noise "exposure" and [illegible] "reaction" [illegible] precisely, and in such a way as to make [illegible] these quantities.

In this paper, considerations affecting the [illegible] variable in community noise research will be discussed, and ways of calculating or determining the most appropriate variable will [illegible]. The variables so obtained will be shown, by reference to data from two separate social surveys conducted by the authors, to be more precise and more valid than those generally used.

Preliminary to this discussion, a brief description of the studies will be given.

OUTLINE OF SOCIAL SURVEYS

The two studies to be discussed are of residents' reactions to aircraft noise and to artillery noise.

The former study entailed a survey of 3,575 respondents around five Australian airports (Hede & Bullen, 1982a), and the latter comprised 1,628 interviews with respondents around a major artillery range near Sydney (Hede & Bullen, 1982b). In both studies subjective reaction was assessed using four separate ratings of "annoyance" (referred to as variables A1 to A4), and two ratings designed to tap a more general reaction (G1 and G2).

A1. A 0-10 rating of annoyance caused by aircraft/artillery noise [illegible] to ratings of other everyday annoyances.
A2. A 0-10 rating of annoyance of aircraft/artillery noise among ratings of other neighbourhood noises.
A3. A 0-10 rating of annoyance due to activity disturbances caused by the noise.
A4. An annoyance rating using verbal categories "highly, considerably, moderately, slightly, not at all .. annoyed".
G1. A 0-10 rating of how much the respondent is "affected overall" by the noise.
G2 A 0-10 rating of how much the respondent is "dissatisfied with the aircraft/army range noise in this neighbourhood".

In addition, both surveys included a question on the number of activities disturbed by the noise (DISTRUBANCES), and one on whether "you feel you would like to" take various complaint actions about the noise (COMPLAINT DISPOSITION). The aircraft noise survey included extra ratings of fear caused by the noise (FEAR), and of how much the respondent's health was affected by aircraft noise (HEALTH). The artillery noise survey included an extra rating of how much the respondent was affected by vibration caused by the noise (VIBRATION).

NOISE REACTION MEASURED AS A CONTINUOUS VARIABLE

Noise reaction - a psychological state of displeasure or dissatisfaction caused by the noise - can be considered to range continuously from a state of no reaction at all to one of extreme reaction. It is therefore natural to ask respondents to rate their reaction on a scale, using either verbal categories or a numerical scale with labelled end-points. Two matters arise in regard to this rating - its reliability, or repeatability, and its validity - that is, whether the rating fully reflects the respondent's complete noise reaction.

Reliability of Individual Ratings

Most social surveys use a rating derived from responses to a single interview question to describe reaction (see Schultz, 1978). It is therefore important to determine the susceptibility of such responses to random errors, due to such things as differing interpretations being given to the particular wording of a question, variations in the exact way in which the question is asked, interviewer errors, etc.

Hall and Taylor (1982), point out that correlations between answers to

different questions in the same interview schedule, each purporting to measure "annoyance", appear to be generally in the range 0.7 - 0.8. They comment that this shows the questions to be "acceptably equivalent". Correlations between the four separate variables used to measure annoyance in the aircraft and artillery noise surveys are shown in Table 1. The size of these correlation co-efficients is generally in agreement with Hall and Taylor's values.

	Aircraft noise survey			Artillery noise survey		
Variable	A2	A3	A4	A2	A3	A4
A1	.818	.751	.724	.757	.652	.629
A2		.828	.769		.760	.719
A3			.821			.818

Table 1 Correlation co-efficients among the four annoyance variables from the two surveys.

However, it must be pointed out that if two variables A and B have an intercorrelation of 0.8, the standard error of estimate for (linearly) predicting A from B is still quite large - 0.6 times the standard deviation of variable A. If A and B are independent, unbiased and equally accurate estimates of a "true" reaction variable R, the standard error for predicting R from either A or B is 0.4 times the standard deviation of R. To put this another way, using the dose-response curve derived from the present aircraft noise survey such an error in measuring reaction is equivalent to a random error of approximately 10 dB (standard deviation) in [illegible] noise exposure.

On the other hard, if two equally-acceptable variables were combined to estimate reaction, the resulting inaccuracy would be equivalent to approximately 7 dB in noise exposure. If four such variables were used, the equivalent inaccuracy would be approximately 5 dB. The actual error in exposure measures for the aircraft noise study was calculated [illegible] 2.3 dB standard deviation.

From this, it can be seen that the error involved in [illegible] individual's reaction from a single interview question can be [illegible] greater than that involved in estimating noise exposure. [illegible]

critical for determining the form of the dose-response relationship, since the errors are presumably randomly distributed with zero mean. However, where knowledge of the real variation in reaction at constant noise exposure is required - such as in determining the effect of non-exposure variables, or in deciding between different measures of exposure - the existence of a large error variance would make such analysis quite insensitive (Bullen and Hede, 1983).

Validity of Ratings of Annoyance

In most studies of community reaction to noise, the term "annoyance" is explicitly taken to be synonymous with reaction (Borsky, 1980). However, some evidence that factors other than those described as "annoyance" are involved in reaction to noise comes from a supplementary survey on aircraft noise (Hede et. al., 1979). In this study, 100 respondents were asked to describe how they feel when they are affected by aircraft noise, and to select words from a list to describe their overall feelings as well as their reaction to specific activity disturbances. It was found that respondents tended to use "annoyance" words (e.g. "annoyed", "upset", "irritated") to describe their reaction to sleep disturbance, conversation interference, TV disturbance and disturbance to reading or studying caused by aircraft noise, but "fear" words (e.g. "frightened", "scared", "concerned") to describe their reaction to being startled or experiencing house vibration.

A more thorough study may be performed using the other two surveys. It is assumed that the questions asking how much the respondent was "affected by" or "dissatisfied with" the noise in the neighbourhood (that is, G1 and G2) include a potentially broader range of possible forms of reaction than those asking specifically about how much "annoyance" is felt. The relative contributions of annoyance, fear, belief in health effects, etc. to overall noise reaction can be gauged from a multiple regression on the responses to the more general questions. The results of such a regression are quite consistent between the aircraft and artillery noise studies, and are shown in Table 2. It is clear that effects which are included under the term "annoyance" make up a large proportion of the overall reaction of respondents. Nevertheless, the small but statistically significant contributions of other variables indicate that "annoyance" is not the only component of reaction to noise.

Survey	Variable	Partial Correlation with (G1+G2) holding higher variables constant	R² after inclusion	Final regression coefficient
	ANNOYANCE (=A1+A2+A3)	.914	[illegible]	[illegible]
	COMPLAINT DISPOSITION	.326	[illegible]	[illegible]
Aircraft	DISTURBANCES	[illegible]	[illegible]	[illegible]
	FEAR	[illegible]	[illegible]	[illegible]
noise	HEALTH	.02[illegible]	(Not statistically significant)	
	ANNOYANCE (=A1+A2+A3)	.876	[illegible]	[illegible]
	VIBRATION	.45[illegible]	.814	[illegible]
Artillery	COMPLAINT DISPOSITION	.28[illegible]	[illegible]	[illegible]
noise	DISTURBANCES	.13[illegible]	[illegible]	[illegible]

Table 2 - Results of multiple regression of various reaction variables on (G1+G2). All variables have been normalized to have the same range. The variable A4 was not included in order that *it be independent* of the final reaction measure in later analysis.

The regression co-efficients shown in Table 2 also provide the weighting factors which are necessary to form a valid scale of general reaction using a large number of interview questions. The procedure used is to combine the two direct measures of overall reaction (G1 and G2) with the estimate of their value derived from the regression equation, the weighting of the direct measures in the overall measure being set at 0.5. This procedure is equivalent to a factor analysis where the direction of the principal component is set on a priori grounds to be the mean of the two direct measures of overall reaction. The resulting measure is referred to as GR.

GR contains the responses to five interview questions with large weightings and responses to a number of others with smaller weightings. It can thus be regarded as considerably more reliable, and marginally more valid, than a single rating of "annoyance".

NOISE REACTION MEASURED AS A BINARY VARIABLE

Although the underlying psychological variable representing noise reaction may be continuous, this is not the variable required by users of the dose-response function - planners, administrators, prospective residents, etc. For these people, noise reaction is of great importance only when it

becomes high enough to stand out among the usual everyday stresses of modern living. In this case, some action - instituting measures to alleviate the noise, choosing a house in another area, etc. - would seem advisable. The relevant reaction variable is therefore binary, representing whether or not this level of reaction has been reached. For this reason, the dose-response function typically shows the percentage of respondents with some relatively high level of reaction.

Such binary variables may obviously be defined from an underlying scale variable by choosing an appropriate threshold or cut-off. The questions of the reliability and validity of such variables need to be addressed.

Reliability of Binary Variables

The reliability of a binary variable will depend largely on the reliability of the underlying scale. The limited reliability of responses to single interview questions can again be seen by comparing binary variables constructed from the three annoyance ratings A1, A2 and A3, using a threshold level of 8/10 or above in all cases. Using the three possible pairs of these variables, it was found that between 13% and 17% of all respondents in the aircraft noise study would receive different classifications depending on which of a pair of these variables was used to classify them. For the artillery noise study, the percentages were between 11% and 16%.

As with the continuous variable, this lack of reliability does not greatly affect the dose-response curve. However, it does have some influence at very low and very high levels of exposure. For example, at low exposure levels there are presumably very few people whose reaction is actually above the threshold, so that any random mis-classifications caused by the unreliability of the reaction variable will be in the direction of mistakenly classifying a respondent's reaction as being over the threshold. This will exaggerate the number of respondents counted as above the threshold at low exposure levels and, conversely, diminish the number at very high levels.

In the aircraft noise study for example, interviews were conducted with 282 respondents in "control" areas between aircraft flight-paths where noise exposure was very low - estimated at about 5 - 10 NEF. Using the three annoyance variables, the proportion of these respondents scoring greater than 8/10 was 13%, 8% and 9%. However, using a scale composed of all three

variables, the proportion scoring over the equivalent threshold was only 6%. This is obviously relevant to discussions of the existence of "supersensitive" and "imperturbable" individuals (see Kryter, 198[illegible]).

Validity of Binary Variables

The validity of binary reaction variables depends not only on the validity of the underlying continuous variable, but also on the threshold chosen. The position of the threshold - described, for example, as "highly annoyed" should correspond with the feelings and reactions normally associated with that phrase.

The only way to investigate the meaning of scores on a reaction variable is to compare these scores with responses to independent questions which elucidate the respondent's feelings about the noise (McKennell, 1963). Such a comparison is made in Table 3 for both the aircraft noise and the artillery noise studies, using the GR scale of general reaction.

Reported Effect or Response	Point on GR Scale: Aircraft Noise Survey	Point on GR Scale: Artillery Noise Survey
Complaint action taken	9.[illegible]	*
Frightened by the noise	**	9.4
Startled by the noise	9.3	[illegible].4
Seriously considered moving house	9.3	*
Self description "HIGHLY ANNOYED"	8.9	9.4
Not adapted to the noise	8.9	[illegible]
Tense or nervous due to the noise	NA	8.[illegible]
Health affected by the noise	8.0	NA
Spontaneous mention of disliking the noise	7.4	*
Self description "CONSIDERABLY ANNOYED"	7.3	[illegible]
Neighbourhood "very bad" for the noise	7.0	NA
Irritable due to the noise	NA	[illegible]
The noise is most worth eliminating	[illegible]	[illegible]
Self description "MODERATELY ANNOYED"	4.9	[illegible]
The noise has increased	4.[illegible]	NA
The noise shakes the house	3.6	[illegible]
Neighbourhood "bad" for the noise	[illegible]	NA
Self description "SLIGHTLY ANNOYED"	[illegible].9	[illegible]
Volunteer the noise as heard in area	[illegible]	[illegible]
Affirm the noise is heard in area	[illegible]	[illegible]

Table 3 - Interpretation of scale scores [illegible] independent [illegible]. Points on the [illegible] GR scale at which [illegible] respondents reported [illegible] effect [illegible] two surveys. NA [illegible] not asked; * [illegible] GR [illegible]; ** [illegible] in GR scale.

Also shown in Table 3 are responses on the five-point verbal annoyance rating scale. It is interesting to note that the point at which [illegible] respondents classify themselves as "highly annoyed" (the highest category on the scale) seems very high compared with the other responses shown. Although the pattern of response is somewhat different in the two studies, the "highly annoyed" point is considerably higher than the level of reaction at which the majority of respondents report health-related effects associated with the noise, spontaneously mention the noise as a feature disliked in the area, and select the noise as the one most worth eliminating from the neighbourhood. In both these studies, it would appear to be more reasonable to set the threshold level of the binary reaction variable at or about GR = 8. Respondents having GR [illegible] 8 may be classified as "seriously affected".

These results are significant in that verbal annoyance rating scales such as that used in these studies are very commonly used to form a binary reaction variable - indeed, Schultz (1978) has specifically recommended that the variable "highly annoyed", determined by self-rating on such a scale, should be used for this purpose. As shown in Figure 1, the dose-response function derived from the aircraft noise study using "highly annoyed" as the reaction variable is in very close agreement with the composite curve derived by Schultz. However, Schultz and others would seem to be unaware of the level of reaction which is implied by the term "highly annoyed". Using the less extreme criterion "seriously affected" results in a dose-response curve showing a significantly higher level of reaction, as also shown in Figure 1. The results in Table 2 indicate "seriously affected" to be a more valid and useful measure than "highly annoyed".

CORRELATION BETWEEN REACTION AND EXPOSURE

It has been specifically argued by Griffiths (1977) and assumed by Fields (1980) and Kryter (1982) among others that the strength of the correlation between a reaction variable and noise exposure provides an indication of the reliability and/or the validity of the reaction variable. However, this argument assumes that reaction is totally determined by exposure, apart from error variance - in Griffiths' words, reaction is not "... conceptually distinct from the exposure". The validity of this assumption is by no means obvious, and it would appear to be at variance with survey results showing a strong influence on noise reaction of other factors, such as "psycho-social variables" (e.g. TRACOR, 1971; Hede and Bullen, 1982a). A reaction

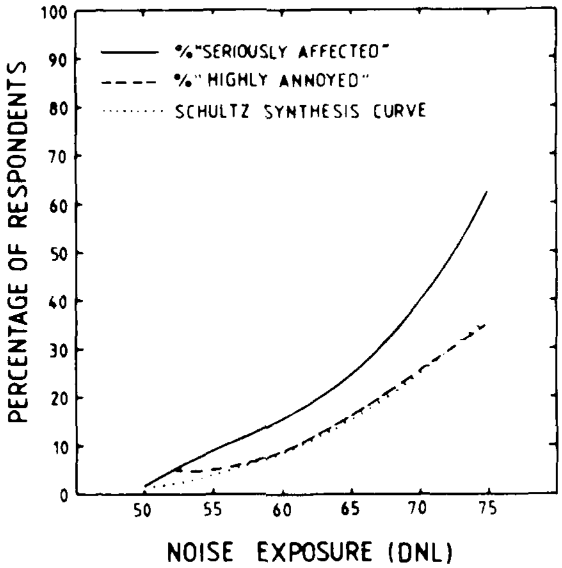

Fig. 1 - Comparison of dose-response curves from the aircraft noise survey using "*seriously affected*" and "*highly annoyed*" as the reaction variable with the synthesis curve from Schultz (1978)

measure which was less influenced by such variation would show a greater correlation with exposure, but would be less valid as a measure of reaction.

In particular, in the choice between binary and continuous reaction variables the correlation with exposure is irrelevant. A binary variable will almost inevitably have a lower correlation with noise exposure than a continuous one - this is the price one pays for using the variable most suited to the user's needs. Similar comments apply to the choice of threshold level for the binary variable.

CONCLUSIONS

Noise reaction - the dependent variable in the noise dose-response curve - is generally measured by a single interview question on serious annoyance. The reliability of this measure, while sufficient to produce a consistent dose response curve, is much lower than the reliability of noise exposure estimates, and can be a limiting factor in other, more complex, forms of analysis (Bullen and Hede, [illegible]). A substantially more reliable, and marginally more valid, measure may be [illegible] of responses to a large number of interview questions [illegible] of subjective reaction.

In producing a binary variable from a [illegible] the level of reaction corresponding to the "[illegible]" [illegible] investigated. The "highly annoyed" [illegible] at which a respondent classified [illegible] "[illegible]" [illegible] scale - appears to represent a more extreme [illegible] generally supposed, and a lower threshold [illegible] more useful measure of high reaction.

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AD-A142 413 NOISE AS A PUBLIC HEALTH PROBLEM: PROCEEDINGS OF THE INTERNATIONAL CONGRE..(U) TURIN UNIV (ITALY) DEPT OF AUDIOLOGY G ROSSI NOV 83 EOARD-TR-84-08-VOL-2 5/6

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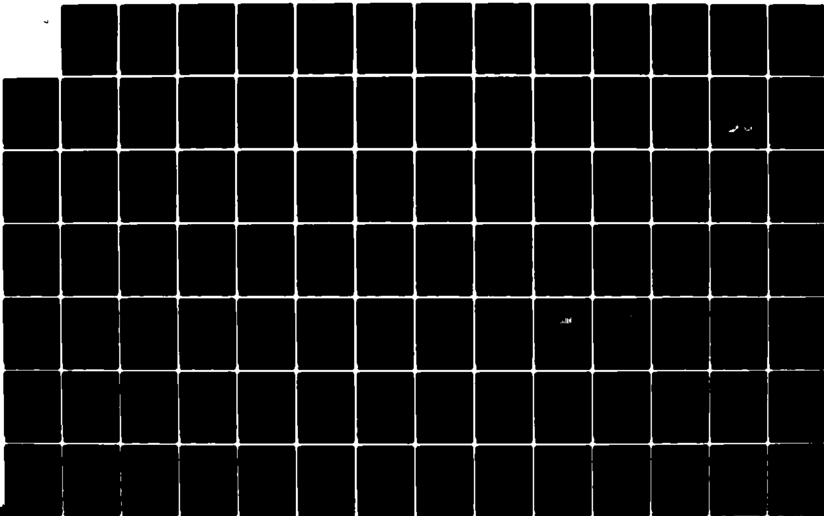

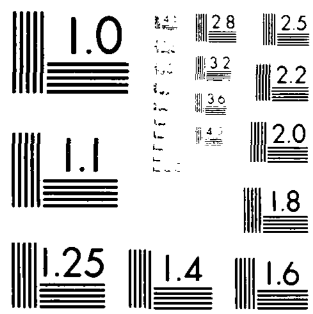

MICROCOPY RESOLUTION TEST CHART

PATTERNS OF BEHAVIOUR IN DWELLINGS EXPOSED TO ROAD TRAFFIC NOISE

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INTRODUCTION

Public authorities are responsible for deciding on a level of noise that should not be exceeded in order that the situation for people living in urban areas will be acceptable in the medium term and improved in the long term.

Given this requirement it is necessary to assess the effects of noise and in fact this matter has been the subject of numerous inquiries over the last 20 years. The early inquiries conducted by Mc Kennel (1), by Langdon in Great Britain (2), by Borsky in the United States (3) and by Lamure in France (4) involved very comprehensive studies of certain aspects of the human responses to noise.

Some of these responses can be verbal and it is possible to arrive at an understanding of what is involved on asking for the opinions of the people concerned. But the verbal expression of annoyance depends on a number of psycho-sociological factors associated with the effects of noise. More, it appears difficult to define what is meant by annoyance.

So a behavioral approach has been attempted to assess, in an objective manner, the impact of noise and find critical levels above which the noise appears to have significant effects.

INQUIRY PROCEDURE

Scale of the inquiry and noise levels involved

The inquiry was concerned with a total of 1500 subjects, of which 94 per cent were women, and who were either the owners or tenants of flats located in a total of 15 different sites. The dwellings were fronted by urban express ways or main through roads in the case of the noisy sites or by service roads in the case of the quieter suburban locations. The inquiry was concerned with a fairly wide range (47 to 77 dB(A)) of noise levels.

Evaluation of the noise levels

The noise levels were determined on the basis of different complementary procedures :

- Measurement of the noise over 24 hour periods at one or two points at each site.
- Measurement of the noise over short periods of time at a number of points at each site.
- Calculation of the noise levels at the facade of each dwelling on adjusting the results of the noise measurements and on making use of the NOISE computer programme developed by IRT-CERNE.

Thus an 08.00 to 20.00 hour Leq value applying to the facade of each room of each dwelling was determined. The Leq values for the evening (20.00 to 24.00 hours) and night-time (00.00 to 05.00 hours) periods were derived from the daytime values on taking account of the results of the single point, long duration measurements of noise at each site.

Items considered in the questionnaire

Following in-depth interviews and a pilot inquiry involving a total of 300 subjects we assumed that the behaviour and attitudes of people could best be observed with respect to the following aspects of daily life within the home :

- The way in which people make use of and organise the available accommodation.
- The health of the subjects and in particular the taking of medicaments.
- The way in which the subjects spend their time, the interest here being in the way noise can affect the duration and distribution of day to day activities (for example, the extent to which subjects leave their dwelling in order to escape from the noise).
- The expenditure either within the dwelling or on the building itself (upkeep of the rooms, sound proofing of the façades).

Given the fairly satisfactory understanding of the relationship between noise and the degree of annoyance as a result of previous inquiries,

it was concluded that we could profit from a study of the relationship between noise and its effects on behaviour.

Analysis of the data

Apart from "conventional" analytical treatment concerned with a correlation of the data and the application of simple χ^2 tests, we also carried out more sophisticated analyses based on the use of procedures such as principal components analysis (PCA), variance analysis and consideration of the results on the basis of various subsidiary classifications of the data.

This last procedure in particular enabled us to determine the noise levels above which there were significant increases in the incidence of the different behavioural responses that were considered.

RESULTS

Annoyance due to the noise

Although the inquiry was concerned in particular with the effects of noise on behaviour it was considered that we should evaluate the degree of annoyance expressed as a result of the noise in order to be able to compare the two kinds of results.

The graph of figure 1 shows clearly that there are two critical daily noise levels, one in the region of 60 dB(A) and the other in the region of 65 dB(A), above which there are more rapid increases in the degree of annoyance with increasing amounts of noise. The same result is obtained on considering the results with respect to various subsidiary classifications.

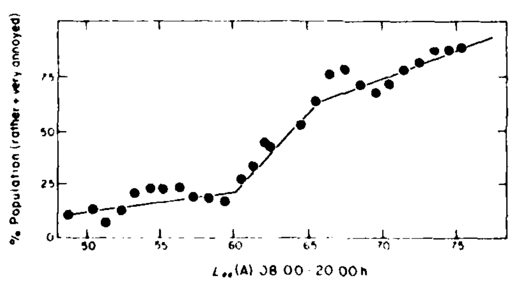

Fig. 1 - Day annoyance and noise : people very annoyed plus annoyed

The results also show that there is a good correlation between the noise level and the degree of annoyance. Thus more than 40 per cent of the variance in the degree of annoyance can be considered to be due to the variance in the noise level.

For night period, it is not so easy to identify the level above which there is a more rapid increase in the degree of annoyance as the amount of noise increases as was the case for the noise occurring during the day although it does appear that the percentage of people who say that they were very annoyed tends to increase more rapidly above a noise level of 52 dB(A) (Leq 00.00 - 05.00 hour).

The correlation between the night-time noise and the annoyance, although not so good as for the daytime case, is still very significant ($r = 0,48$).

Behaviour in response to the noise

• Use of the dwelling

First, it was found that windows tended to be closed more particularly when watching television, when reading and before going to sleep (figure 2).

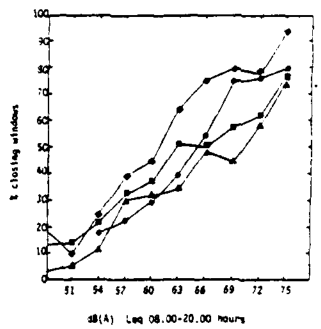

Figure 2 - Percentage of people closing their windows for : watching TV (♦), conversation (●), sleep (■), lecture (▲)

Fig. 2 - Percentage of people closing their windows for : Watching TV (♦), conversation (●), sleep (■), lecture (▲).

As regards the transfer of activities susceptible to the effects of noise, to quieter rooms, it was found that the critical noise level above which there was a significant response during the daytime period amounted to Leq > 68 dB(A). The activities mainly involved here were reading and work of an intellectual nature carried out in the home, these being activities that can often be transferred from one room to another without too much difficulty. On the other hand there was no significant transfer of activity so far as watching the television or sleeping was concerned. Clearly there are difficulties with regard to the transfer of these last two activities, either because of the lack of a spare room or because of the physical difficulties involved in moving an item of equipment such as a television set to another room.

• Effect of noise on sleep and health

This study was more concerned with the indentification of simple indicative prameters and the determination of critical noise levels. The indicative parameters were concerned with the conditions that can apply on going to sleep : time taken in getting to sleep, difficulties in getting to sleep, taking of sleeping tablets and the extent to which noise results in the subjects waking up during the night.

The results lead us to the following conclusions :

- Noise appears to have a much more pronounced effect in waking people up than in preventing them from getting to sleep, this latter difficulty being more closely related to the age of the subjects.
- The interference with sleep leads to an appreciable increase in the taking of sleeping tablets although there appears to be a stronger connection with age here than with the presence of noise

(13 per cent of people taking sleeping tablets for noise levels of 50 dBA and 20 per cent when the noise level amounts to 75 dBA).

Although there is only a slight correlation between the noise and some of the indicative parameters it should be noted that the critical noise levels above which there are more rapid increases in the interference with sleep, are the same for all of these parameters. Thus to consider just two critical levels, there are rapid increases in the effects for all of these parameters above Leq values of 45 and 55 dB(A) for the 00.00 to 05.00 hour period which correspond to Leq values of 55 and 65 dB(A) for the 08.00 to 20.00 hour period.

If we consider medicament consumption not only on going to bed but also during the day then, as shown by figure 3, it will be found that there are rather significant relations with the level of noise.

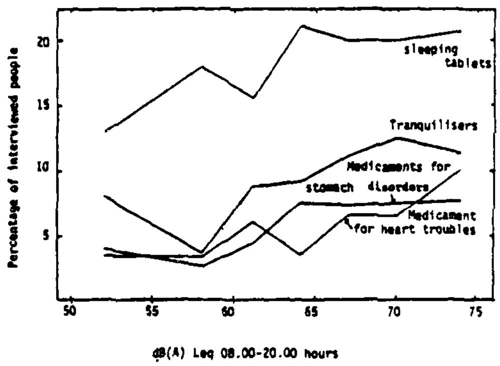

Fig. 3 - Medicament consumption versus noise

If we consider some subsidiary classifications of the subjects with regard to the taking of sleeping tablets it can be seen how this practice is related to sleeping difficulties. Thus subjects who have difficulties in getting to sleep are much more likely to take sleeping tablets : 33 per

cent compared with 10 per cent in general and 57 per cent when the subjects are more than 65 years of age. In this latter case, the presence of noise simply reinforces the behaviour, the percentage of subjects taking sleeping tablets rising to 69 per cent for noise levels of Leq > 65 dB(A). On the other hand, subjects that tend to get to sleep fairly quickly seldom take sleeping tablets, particulary if they are young (less than 5 per cent).

• Sound proofing of the dwelling

Figure 4 shows clearly how the percentage of dwellings that have been sound proofed increases with the noise level :

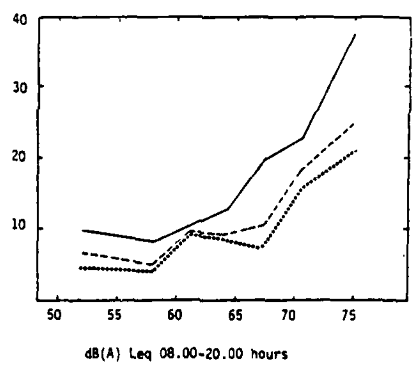

Fig. 4 - Percentage of sound proofed dwellings versus noise :—— owners ; .... tenants ; - - - total sample.

A number of different factors are involved here like the income of the household, the occupation status (owner occupier or tenant), the length of occupation.

• Escaping from home

The results indicated that whereas the noise did not give rise to families going out any more, either during the week or at week-ends,

(which would have been a useful indication of attemps to escape from the noise) it did lead to some families considering the possibility of moving. However although the noise was involved to some extent here it did not appear to be the main reason for moving.

The analysis of this type of response was delicate, namely the intention to move to another dwelling, but we can nevertheless draw the following conclusions :

- The status of occupation of the dwelling has a dominant effect ; thus not only is it easier for a tenant, as opposed to an owner of a property, to move (no difficulties with regard to the selling of the property) but there may be other obvious reasons for moving apart from the question of noise (need to find more suitable accommodation, desire to purchase a house, etc.).
- On the other hand the amount of a low rent to be paid and the difficulty of finding equivalent accommodation can discourage a tenant from moving.
- Finally we come to the effect of noise which becomes more pronounced for levels above 66 to 68 dB(A) and when it is found that a low rent is not enough to prevent tenants from moving. Thus it would appear that there cannot be any monetary compensation for the higher noise levels.

It should also be noted that the fact that he has sound proofed his dwelling is likely to discourage an occupant from moving.

Thus th two behavioural responses of sound proofing the dwelling or moving, which are both more likely to arise for noise levels of more than 66 to 68 dB(A), can be regarded as alternative possibilities.

CONCLUSIONS

In this study we attempted to assess the effects of road traffic noise on considering the adaptive or evasive behavioural responses to such noise.

As a result of the study it is possible to come to the following conclusions :

1. Below 55 dB(A) for the daytime value of Leq it can be assumed that the noise gives rise to little or no disturbance and that the level of noise is such that activites that are most likely to be affected by noise can be carried out quite normally.
2. Between 55 and 60 dB(A) the effects of the noise are still acceptable but people who are most sensitive to noise are beginning to be disturbed.
3. Between 60 and 65 dB(A) we begin to see some bahavioural responses that are not as yet very forced (e.g. the closing of windows to shut out the noise). However the effects with regard to sleeping and the degree of annoyance that is experienced increase very significantly. It is desirable that action be taken to reduce the noise level but the results of a cost-benefit analysis of such action will not necessarily be very positive, at least in the case of palliative measures such as the provision of sound barriers or the application of sound proofing treatment.
4. Above 65 dB(A) we begin to see compulsive behavioural responses which are indicative of severe disturbance due to the noise (transfer of activities to quieter rooms, sound proofing of dwellings, moving to other accommodation). Action by the public authorities in this case is not only desirable but essential particularly since

in most cases the net economic benefit of any action has every chance of being positive for the community as a whole.

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GUIDELINES FOR AUDITORY WARNING SYSTEMS ON CIVIL AIRCRAFT: A SUMMARY AND A PROTOTYPE

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INTRODUCTION

The purpose of the auditory warning system on the flight-deck of a commercial aircraft is to alert the flight crew to dangerous conditions, to potentially dangerous conditions, and to the arrival of information on visual displays. All of the current warning systems perform the alerting function with exceptional reliability; furthermore, in the vast majority of cases, the information specifying the type of problem is successfully communicated. But the existing systems achieve their success at considerable cost, in that they typically flood the flight-deck with very loud, strident sounds. This has two unfortunate side effects: First, it makes the auditory warning systems unpopular with flight crew. Second, and perhaps more important, many of the existing warnings disrupt thought and prevent crew communication, which at a critical moment makes an already difficult situation worse.

In a recent report, a set of guidelines were developed

for auditory warning systems on civilian aircraft that enables the designer to avoid these side effects and produce much more ergonomic warnings. The current paper presents a summary of the guidelines, and then a description of a prototype warning that illustrates the guidelines.

GUIDELINES

1. The Overall Level for Flight-Deck Warnings

The lower limit for the range of levels appropriate for the prominent spectral components of auditory warning sounds is 15 dB above the threshold imposed by the background noise on the flight-deck. The upper limit for warning-sound components is 25 dB above threshold since the levels imposed by the noise in level flight are already rather high. For many civil jet aircraft threshold on the flight-deck, P_s, can be calculated as a function of filter centre-frequency, f_c, using the equation

$$P_s = 0.15\ f_c\ NL,$$

where NL is the average spectrum level of the background noise in the region about f_c. The level-flight phase of flight is usually the loudest. Note, NL is in (dynes/cm^2)/Hz in this equation. The original report (Patterson, 1982) includes methods for calculating threshold in noise environments having complex spectra.

2. The Temporal Characteristics of Flight-Deck Warnings

The pulses of sound used to build a warning sound should have onsets and offsets that are 20 - 30 ms in duration. The

gating function should be rounded and concave down. The sound pulses should be 100 - 150 ms in duration. For urgent warning sounds the inter-pulse interval should be less than 150 ms. For non-urgent warnings the interval should be over 300 ms. The warning sound should be composed of 5 or more pulses in a distinctive temporal pattern to minimise the probability of confusion amongst the members of the warning set.

3. The Spectral Characteristics of Flight-Deck Warnings

The appropriate-frequency region for the spectral components of flight-deck warnings is 0.5 - 5.0 kHz. The warning sounds should contain more than four components and the components should be harmonically related so that they fuse into a concise sound. The fundamental of the harmonics should be in the range 150 - 1000 Hz, and at least four of the prominent components should fall in the range 1.0 - 4.0 kHz. For immediate-action warnings the sounds might contain a few quasi-harmonic components and/or a brief frequency glide to increase the perceived urgency of the sounds.

4. Ergonomics

Automatic volume control should be restricted to a range of 10 - 15 dB and used primarily to reduce the volume when the aircraft is on the ground or in the climb or approach phases of flight. There should be no more than six immediate-action warning sounds and three attensons (i.e. attention demanding sounds).

5. Voice Warnings on the Flight-Deck

Voice warnings incorporated into immediate-action warnings should be brief and use a key-word format. They should not be repeated in the background version of the warning. Voice warnings used in less urgent warnings should use a full-phrase format and be repeated after a short pause. The frequency range appropriate for warning-sound components is also appropriate for speech (0.5 - 5.0 kHz). The appropriate level for voice warnings can be achieved by positioning the maximum of the average speech spectrum (typically the components of the first formant) near the maximum of the appropriate-level range for warning components. In the region 0.5 - 5.0 kHz, a progressive amplification of about 3 dB per octave will improve the speech intelligibility.

PROTOTYPE WARNING

The temporal structure of a warning that might be used to designate the condition 'undercarriage unsafe' is presented in the diagrams of Figs. 1 and 2. They show, respectively, the basic pulse patterns used to represent the warning, and the time course of the complete warning. In Fig. 1 each rounded hump represents a pulse of sound about one tenth of a second in duration. The waveform within the pulse is unique to a particular warning; it carries the spectral information of the warning sound and is never altered. A burst of six pulses defines the warning sound. The basic grouping of four, clustered pulses followed by two, irregularly-spaced pulses provides the rhythm of the sound which, combined with the spectral

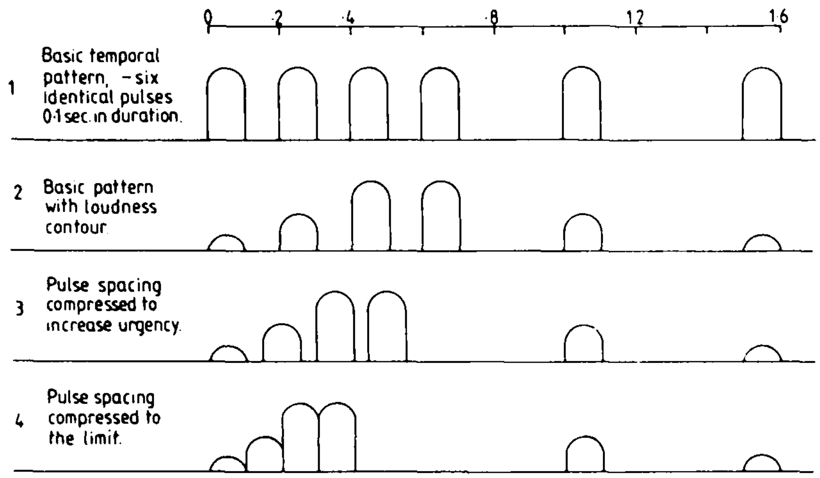

Fig. 1 - Time course of bursts of pulses for an auditory warning.

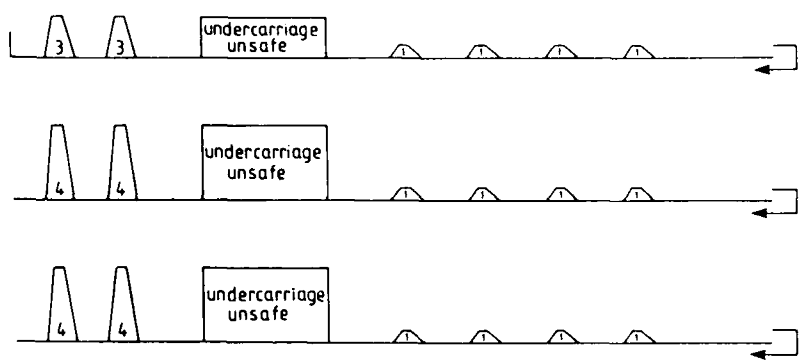

Fig. 2 - Time course of a complete auditory warning.

characteristics stored in the waveform, gives the sound its distinctiveness. The four rows of Fig. 1 show how the spacing and intensity of the pulses can be varied within the burst to vary the impression of urgency and avoid abrupt onsets. Each trapezium in Fig. 2 represents one play of the warning sound,

1. Overall level

The warning comes on at a moderate level, well above the minimum required to draw the crew's attention, but well below the level where it would be aversive. The warning is repeated and then a voice warning presents the same information. A detailed method for determining the levels is presented in the original report.

At this point the warning is turned down automatically to a level that is still audible but which can be overridden by a person speaking loudly. The warning stays in the background at the lower level for a reasonable length of time, depending primarily on the urgency of the condition, but if the fault is not corrected the auditory warning and the voice warning both return (the second row of Fig. 2) at the maximum of the appropriate range for warnings.

that is one row of Fig. 1; the number in the trapezium indicates the row. The duration of a row in Fig. 2 is about 20 times that of Fig. 1, or about 32 seconds. The rectangle represents a voice warning and the heights of the rectangles and trapeziums indicate the relative intensities of the various components. When conditions dictate, the warning is initiated and proceeds as follows:

2. Temporal characteristics

An arresting warning can be produced without risking a startle reaction by bringing the warning on at a comparatively low level and increasing the level of successive pulses quick-

ly as shown in the second and successive rows of Fig. 1. This amplitude envelope gives the impression that an object is moving towards you rapidly and then receding slowly, and this apparent motion draws your attention. At the same time, since the first pulse comes on at a moderate level, the warning does not cause a startle reaction. The basic pulse is similarly given a rounded top rather than an abrupt onset or offset to reduce the risk of a startle reaction.

The version of the basic burst shown in the first row of Fig. 1 does not sound particularly urgent when played at a moderate level and at the rate indicated. More urgent versions of the same pattern are obtained by compressing the first four pulses in time as shown in the last two rows of the figure. So long as the warning is composed of a group of four regular beats followed by two irregular but fixed beats, and the waveform within the pulse is not changed, it will sound like the same warning. In Fig. 2, the '3' in the first pair of trapeziums indicates that the warning is initiated in the version that gives the impression of moderate urgency. After the voice warning it is changed to version '1', which sounds less urgent when played at a lower level because the first group of pulses is well spaced and they are all the same level. But if the fault condition is not corrected the warning returns in the most urgent form '4' which, combined with the maximum level, commands attention.

3. Spectral characteristics

Where possible, to provide continuity between existing

and future warning systems, the basic pulse of a new warning should be taken from the sound assigned to the same function in the system it replaces. This can be accomplished by digitising a sample of the original sound, selecting an appropriate subsection, and rounding the onset and offset with a raised-inverted-cosine gating function. In this way the original association of sound and function can be preserved while at the same time implementing the other improvements.

4. Voice warnings

In the immediate-action warning, the role of the voice warning is to present one, highly redundant, repetition of the warning's information to eliminate the possibility of confusion; in this way the major advantages of speech are incorporated into the system. The voice warning is not repeated when the warning switches to background mode because it would be intrusive and increase the total on-time unnecessarily. It is also difficult to produce a background-level voice warning because of the large dynamic range required for speech. The vowels of speech are often 30 dB more intense than the consonants, and so if a voice warning were attenuated to produce a background version with the correct vowel level the consonants would be near or below masked threshold.

CONCLUSIONS

Many existing auditory warnings are needlessly aversive and could be replaced with more ergonomic warnings generated with the aid of some fairly simple guidelines.

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ACKNOWLEDGEMENTS

I wish to express my sincere gratitude to Dr. Irv Pollack who presented this paper for me at the conference and encouraged me with his infectious enthusiasm to produce the written paper.

PROPOSAL FOR A SCIENTIFIC PROGRAM

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At a meeting of the team, the following six recommendations were generally agreed:

1. Shrinking resources emphasizes the need to expand the joint and coordinated research efforts of the EEC to other investigators in other nations. This will enable avoidance of duplication and facilitates the combination of comparable data under a greater variety of conditions than ould be possible for any single study.

2. Cooperation and coordination among members of Team 6 and Team I and possibly other teams is indicated by the need to develop a total profile of noise exposure. Team I complains that calculation of hearing loss due to occupational exposure is compounded by lack of data on noise exposure in the residential community, etc. Likewise, the expectations and attitudes of resident toward community noise is probably influenced by their daily noise at work. The availability of recorders may facilitate miniature acoustic total monitoring.

3. More attention and greater precision of measurement is needed of the acoustic environment, especially with a variety of noise sources and ambient conditions. There is still a need for more accurate noise descriptors that are related to both acoustic and human perceptions and

responses. It is likely that no one descriptor can sufficiently be related to all complex community situations.

4. Additional development should be encouraged of methods to scale response variables such as annoyance and negative reactions to the noise sources.

5. More sophisticated experimental designs should be utilized, whenever possible, such as longitudinal studies of before and after changes in the acoustic environment. This would include evaluations of the effects of noise abatement actions on the noise conditions and human awareness and reactions to changes.

6. Secondary analyses and testing of new hypothesis based on completed studies may prove useful. NASA Langley Center in the U.S. is attempting to establish a data bank of original raw data. Investigators are urged to contribute their data and to use the data bank in planning new studies.

Poster Session

REACTION TO AIRCRAFT NOISE NEAR GENERAL AVIATION AIRFIELDS

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INTRODUCTION

The Noise and Number Index (NNI-Reference 1) is the official noise exposure index used in the UK. It is defined as $NNI = L + 15 \log N - 80$ where L and N are respectively the logarithmic average noise level in PNdB and the number of aircraft producing noise levels ≥ 80 PNdB on the ground in the reference period 0600-1800 hours GMT on "an average summer day". The derivation and validation of the NNI had been based on social survey/noise measurement around major commercial airports; doubts were therefore expressed about the use of the NNI as a measure of community annoyance around General Aviation (GA) airfields with lower noise levels and different patterns of traffic. Consequently the Civil Aviation Authority (CAA) carried out (on behalf of the UK Department of Trade) a study (Reference 2) at a number of representative GA airfields in order to establish the nature and scale of disturbance and to determine how adequate existing noise indices (in particular NNI and Leq) were in describing this disturbance; and what modifications to the indices, if any, might be necessary.

DESIGN OF THE STUDY

From an initial list of 27 possible UK airfields five were chosen for the study. They were Coventry (60,000), Kidlington (150,000), Leavesden (30,000), Shoreham (75,000) and Staverton (45,000); the brackets containing the approximate number of annual movements for the last available year.

These airfields are almost "pure GA" airfields with no large numbers of commercial, military or helicopter movements. There is a substantial proportion of "touch-and-go" movements associated with circuit flying at three of the airports (particularly at Kidlington where about 110,000 movements were of this type. The study comprised a social survey allied with noise measurement in one area near each airfield: 5[illegible] individuals were interviewed. The study was originally designed on the basis of a random sample within each area, each being a "common noise" area. The concept of a "common noise" area is that all respondents within the area experience the same noise exposure (to within about 3 dB) and this noise exposure can be determined by measurement at one central point within the area. It was found necessary, in order to provide a sufficient population for valid sampling, to make the areas somewhat larger than "common noise" areas, noise measurements being made at six sites within the area in order to identify variation in noise exposure.

NOISE MEASUREMENT AND SOCIAL SURVEY

The bulk of the noise measurement was made using unattended automatic measurement equipment - the Digitronix Nomal 2B - over a period of at least 10 days at each site: noise events were matched to aircraft by using the airfield movement records. All measurements were made on the dBA scale, peak levels and duration being recorded so that estimates could be made of L_{AX} values. (The data base for calculating values of NNI consists of measurement on the dBA scale - values of PNdB being obtained by adding a constant 13 dB.) The questionnaire used for the social survey interviews was based to a large extent on that used in previous studies around Heathrow. In particular the questionnaire contained the standard set of questions from which two principal measures of annoyance can be obtained. The first is a respondent's score on the Guttman Annoyance Scale (GAS)*: the questions underpinning this scale and the scoring method has been included in a virtually unchanged form in nearly every UK study of annoyance from aircraft noise since 1961. Variants of the scale containing extra questions (appropriate to GA activity) were also assessed. The second measure is a respondent's reaction on the Aircraft Noise Annoyance Scale (ANAS). This is a semantic scale where a respondent is asked how much he is bothered/annoyed by aircraft noise - 'Very Much'; 'Moderately'; 'A Little'; 'Not At All'.

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*The respondent is scored on his answers to questions relating to aircraft-induced annoyance or disturbance of activities/states. The scale is from 0 to 6 (highest annoyance).

RESULTS

The noise exposure for respondents at the four airfields other than Leavesden is about 5 NNI at Coventry, [illegible] NNI at Kidlington and typically 22 NNI at Shoreham and Staverton. Responses at each of these four airfields are very similar, however assessed, and markedly less than the responses at comparable exposure found in the [illegible] Study areas [illegible] Heathrow. At Leavesden, responses from those exposed to [illegible] NNI were not statistically different from those for respondents in the same NNI band surveyed in the Heathrow Study. However above [illegible] NNI respondents were <u>more</u> annoyed than comparably exposed people at Heathrow in [illegible]. There was no indication from this study to indicate that modifications to the NNI are necessary to account for training circuits or noise levels on the ground less than 80 PNdB. Responses in general at Leavesden were markedly different from those at the four other airfields, for example:

	Leavesden	Others
Aircraft noise as a reason for disliking neighbourhood	[illegible]	[illegible]
Local flying shows good concern for community	[illegible]	[illegible]
All things considered, aircraft noise is acceptable	[illegible]	[illegible]

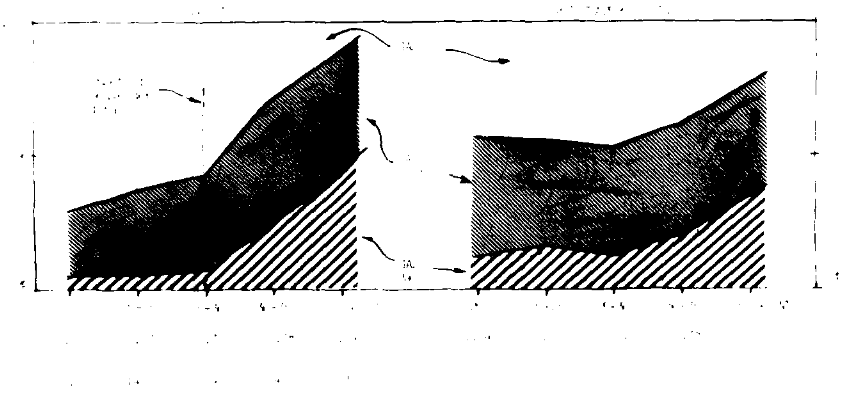

Figure 1: [illegible]

[illegible] in Figure 1 and compared with the results from the [illegible]. [illegible] and Leq are in any case highly correlated here.

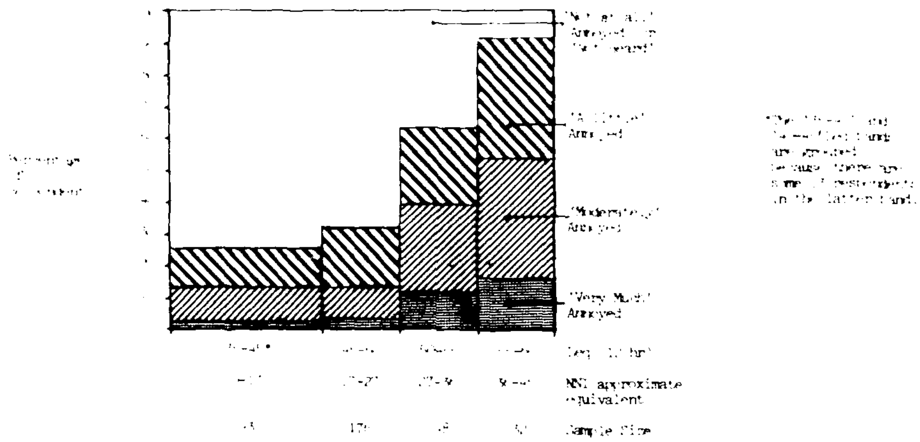

Figure 2: Aircraft Noise Annoyance Scale (ANAS) responses versus Leq.

CONCLUSIONS

The GAS score is an adequate measure of annoyance for GA airfields and demonstrates annoyance to a greater degree than the Aircraft Noise Annoyance Scale. The variants of GAS examined did not provide a markedly better scale. GAS scores in areas of low exposure (below 30 NNI) are only weakly correlated with NNI or any other noise exposure metric tested; above 30 NNI they are well correlated - at levels above 35 NNI the responses to GA are more marked than at Heathrow. It was not possible to determine if any other index would perform better than NNI above the level 30-35 NNI, because NNI, Leq, logarithmic average noise level and number of movements are highly correlated for the Leavesden respondents.

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(All Directorate of Operational Research and Analysis (DORA) Civil Aviation Authority, London, UK)

ANNOYANCE RATINGS FOR IMPULSE AND TRAFFIC SOUNDS IN BACKGROUND NOISE

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INTRODUCTION

The research reported in this paper focuses on four factors, which may be relevant in the evaluation of general aversion to noise. The first aspect refers to the *impulse versus continuous* character of the noise. To compensate for the impulse character of noises, a penalty of 5 dB has been recommended by ISO/R 1996 (1971). This penalty has to be added to the A-weighted equivalent sound level in order to get the equally annoying continuous noise level. The second aspect refers to the *level* of the noises. In a C.E.C. joint research project (Rice, 1983) it was found that for annoyance due to sounds in quiet, C_{imp} is level dependent and decreases from about 10 dB at a level of 35 L_{Aeq} to 0 dB at an L_{Aeq} of 70 dB. The need for an impulse noise correction factor is also strongly supported by results from a C.E.C. joint field study. From their preliminary data (de Jong & Groeneveld, 1983) it can be revealed that this penalty is equal to about 9 dB for residential areas where the overall noise level is below 57 dB and equal to 6 dB for higher overall noise levels. The third aspect is concerned with the level of the *background noise*. While the annoyance, attributed to a particular intruding noise may depend on the level of the background noise, it is not a priori clear to which extent C_{imp} is influenced by it. This may depend on whether *source-specific* annoyance or *total* annoyance has been assessed. We decided to include this nonacoustical factor as well.

MATERIAL AND METHODS

The gunfire noises were digital recordings of a pistol fired in a reverberating room. These shots were regenerated at variable intervals. For the first type of gunfire noise (G1) the mean interval between the shots was equal to 2 sec, the standard deviation was .[illegible] sec. For the second type of gunfire noise (G2) these values were 1.5 and 1.6 sec, respectively. The metal construction noise (C), recorded in the neighbourhood of a container repair shop, comprised various noises such as hammering, banging, drilling, and grazing. Since actually, high levels of close traffic noise are characterized by large and rapid fluctuations in level and low levels of remote traffic noise comprise small and slow fluctuations, various recordings were made, one for each level of sound intensity. The background noise, being presented throughout the experimental session, was a special recording of traffic noise with a very stable noise level.

Sixty-four subjects, 36 males and 28 females, between 18 and [illegible] years of age, participated in the experiment. While reading a book, magazine, or newspaper, they were presented with the sounds by means of a Quad electrostatic loudspeaker. The soundproof room ([illegible].5 x 4.5 m) was fitted with a window and with sound absorbing walls.

The independent variables were: (1) type of instruction (rating of source-specific and total annoyance); (2) background noise level (35 and 55 dB,L_{Aeq}); (3) signal level (for the lower background noise level: 30, 40,50, and 60 dB,L_{Aeq}; for the higher background noise level: 40,50,60, and 70 dB,L_{Aeq}); (4) signal type (gunfire I, gunfire II, metal construction, and traffic noise). Both type of instruction and background noise level were varied between subjects. Signal level and signal type were varied within subjects.

In addition to the general information, how to use the ten-point equal-interval scale, the source-specific annoyance group received the following instructions: 'We want you to give an assessment of the additional noise you have heard the last five minutes, thus irrespective of the constantly present background noise. How annoying would you find this noise if you would hear it all the time in the living room against the same kind of background noise ?' For the total annoyance group these instructions were: 'How annoying would you find the total noise you have just heard, if you would hear it all the time in the living room ?' To make sure that it was clear to the subjects from the first group, which sounds were intended to be additional, short samples of the four noise types were presented without background noise, before entering the experimental room.

RESULTS

It can be seen from Figure 1 that for the four groups, each representing a different combination of the two background noise levels and the two types of instruction, the annoyance ratings increased with increasing signal or total noise level ($p < .00001$). Averaged across level, traffic noise is rated lower than the other three noises ($\alpha < .05$) for all groups. For three groups, the annoyance rating due to low level construction noise was in between that caused by gunfire and traffic noise, whereas for high

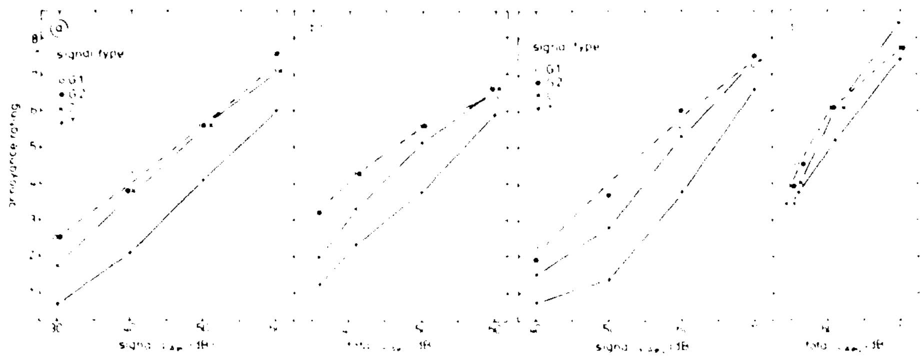

Fig.1. Source-specific annoyance, plotted as a function of signal level (panels a and c) and total annoyance, plotted as a function of total noise level (panels b and d). The L_{Aeq} of the background noise was 35 dB in panels a and b, and [illegible] dB in panels c and d.

levels, the ratings for construction noise equaled those for the gunfire noises. Dose-response relationships, as depicted in Figure 1 can be described adequately by means of the function $y = a + bx$, where y represents the annoyance rating and x represents the signal level or the total noise level in decibels. If for impulse noise the dose-response relationship is given by $y = a_1 + b_1x$, and for traffic noise, this relationship is given by $y = a_2 + b_2x$, then for each level, x, of the impulse noise, the correction, C_{imp}, which has to be added to the noise level to get the equally annoying traffic noise level, is equal to

$$C_{imp} = \{ a_1 - a_2 + (b_1 - b_2)x \} / b_2 . \qquad (1)$$

With the help of Equation 1, penalties for impulse noise were computed for all conditions. The obtained values are given in Table I. For source-specific annoyance in the high background condition, the dose-response relationship for traffic noise was based on only the three highest signal levels. The lowest level was excluded because at this condition, the traffic noise could not be discriminated from the background. The fact that this condition did not render lower ratings is due to a floor effect.

With respect to low signal levels our penalties for gunfire noise are in line with results for sounds in quiet (Rice, 1983). However, our data do not suggest that no penalties are needed for very high sound levels. This is supported by data from a field study (de Jong & Groeneveld, 1983).

Table I

Impulse noise corrections, given for gunfire (G1+G2) and metal construction noise and for various levels of the noises.

Source-specific annoyance rating

background noise level (L_{Aeq},dB)	noise type	signal level (L_{Aeq},dB) 30	40	50	60	70
35	gunfire	11.0	9.9	8.8	7.7	(6.6)
	construction	7.2	7.4	7.6	7.8	(8.0)
55	gunfire	-	13.2	10.1	7.0	3.9
	construction	-	9.4	7.4	5.3	3.3

Total annoyance rating

background noise level (L_{Aeq},dB)	noise type added to background	total noise level (L_{Aeq},dB) 35	40	50	55	60	70
35	gunfire	11.9	10.5	7.6	6.1	4.7	(1.8)
	construction	4.9	5.0	5.1	5.2	5.3	(5.4)
55	gunfire	-	-	3.6	3.1	2.6	1.7
	construction	-	-	0.1	1.1	2.0	4.0

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ACKNOWLEDGEMENTS

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Team No. 7
Noise and Animals

Chairman: R.G. Busnel (France)
CoChairman: J.L. Flechter (U.S.A.)

Invited Papers on Specific Topics

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EFFECTS OF NOISE ON WILDLIFE: A REVIEW OF RELEVANT LITERATURE 1979-1983

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Previous reviews of the literature relevant to the effect of noise on wildlife have been made by Fletcher et al (1971), and Fletcher (1980). A bibliography, "The effects of noise and intense sounds on nonhuman primates: A bibliography.", has been collated by the Primate Information Center, University of Washington, Seattle, Washington (1980). Other than those literature review-literature search efforts, there is no evidence of any systematic organized effort to delineate the nature and magnitude of the effects of noise on wildlife and other animals. Possibly Busnel (personal communication) hit upon some of the thinking behind the shocking lack of interest and effort in this direction. His opinion on this matter was that essentially, only the North American Continent has both the wildlife and any organized concern for their survival, and even then, there are so many problems receiving higher priority that no research attention has been paid to the noise and wildlife problem. Whatever

and collagen content of the rat heart with chronic magnesium deficiency and stress. They found that rats with chronic magnesium deficiency have less magnesium and potassium in heart muscle tissues. They also report a calcium, sodium, and hydroxyproline increase, as well as an increased urinary excretion of adrenaline and more particularly, noradrenaline. They found that with simultaneous noise stress the changes increased with degree of magnesium deficiency. The noise stress to which the rats were subjected consisted of 12 hours per day of tape recorded traffic noise at an L_{eq} of 69 dB relative to the rat hearing threshold with a maximum of 85 dB, and an L_{eq} of 73 dB with L_{max} of 86 dB in a second series. The noise exposure was begun four weeks after the magnesium deficit was initiated. It would seem apparent from the results of this study that interactions of noise stress and various aspects related to every day living such as diet can, and probably do occur in the environment and can result in damage to wildlife and other animals from levels of noise that might normally not be expected to be of concern.

A survey of the impact of continuous noise on animal health was made by Algers et al 1978. In the introduction to their survey they pointed out that the environmental conditions of domestic animals have changed drastically over the last several decades, with noise level one of the more obvious changes. Their review was for effects of continuous noise, which does not have a "markedly intermittent" nature and is "not characterized by short sound blasts." Their survey of noise effects revealed rabbits exposed to 1500-3000 Hz

sound at 90-93 dB for 152 days had EEG changes. Specifically, the EEG changed from the normal slow high amplitude pattern to high frequency oscillations of 60-75 Hz during the first day of exposure, then a rhythm of 5-6 Hz at 100-178 micro-volts amplitude developed. This rhythm corresponded to breathing rhythm. Cats in white noise showed a marked increase in inferior colliculus activity, while pure tone stimuli produced a decrease in activity, with maximum response to 1000-2000 Hz tones. They also noted that O_2 consumption in the brain decreased in proportion to exposure time to the noise. In rats they found data suggesting that permeability of the blood-brain barrier develops after noise exposure, and that metabolism of macromolecular phosphorous products is also changed by noise exposure. Rats exposed to 80 dB showed intensification of the oxidizing process which researchers felt increased synthesis of macroergic phosphorous components and at 97 dB they noted the oxidizing process was interrupted in the brain and inner organs. They also found literature reporting noise effects on the eye. Studies noted that nystagmus and eye velocity changes were observed under noise stress and that sudden noise caused pupil dilations. Glandular changes have also been observed, with the hypophysis and adrenal glands stimulated by noise above 68 dB and causing changes in adrenocortical activity in rats, mice, and guinea pigs. The adrenals of mice have been seen to hypertrophy, and the weight of the adrenals increases in older noise-exposed rats, while decreasing in younger rats. They also reported increased levels of

the reason, this review included a detailed literature search as well as a personal canvas of people known or thought to be working in this area. It may be of interest that the extensive computerized literatare search produced considerably fewer relevant studies than did the call for help to scientific colleagues.

As found in the last literature review regarding the effects of noise on wildlife, special situations evolve which then forceably focus scientific attention upon problems of noise and wildlife. In the last review, the problems brought about by the MacKenzie gas pipeline from Alaska through Canada generated a considerable amount of relevant study on wildlife reaction to noise. For this review, concern by native Alaskans resulted in a workshop specifically convened to consider interaction between manmade noise and vibration and arctic marine wildlife. While this workshop was not a research undertaking, it was a coordinated effort that included scientists from several disciplines relevant to the problem as well as concerned and knowledgeable citizens. The purpose of the workshop was to assess the current state of knowledge regarding noise and arctic marine wildlife and make recommendations for research to be done to fill in gaps in scientific knowledge of the subject. The workshop was funded by the Alaska Eskimo Whaling Commission.

Review of Literature

This review will consider the literature chronologically. Gunther, Ising, and Merker (1978) studied the electrolyte

corticosteroid hormones.

Liver changes were found as well. After exposure to 105 dB of 300-3200 Hz noise for two weeks, an increase in liver weight was found, with more RNA soluble proteins, and no change in DNA. Hypertrophy of special cells in the liver occurred after 4 weeks of stimulation, other changes were noted in various enzyme and chemical processes as well. For example, after a short noise exposure, an adrenalin secretion connected with hypoglycemia was found, probably due to noise causing metabolization of mobilized liver glycogen then, secondarily, hypoglycemia.

Studies were also reported that found kidney changes after noise exposure. Liver changes change the metabolic concentration in blood, which increases the kidney work load and therefore produces changes in kidney enzymes after noise exposure. For example, aldosteronism and water retention were seen in pigs exposed to 93 dB noise for several days.

Changes in the genitalia have been noted as well. Studies report an increase in weight of ovaries, others a decrease. The estrous cycle in various female animals seems to be changed by noise, and both male and female fertility appear to be diminished by noise exposure.

The circulatory system was also found to be susceptible to noise exposure effects. Cardiac hypertrophy and hypertension were seen after exposure to 83 dB of 20-25,000 Hz noise for three weeks. Various EKG changes such as changes in the shape of the R and T waves were observed.

Changes in blood have also been seen following noise exposure, with eosinophils decreasing, then increasing in rats, but not returning back to their original level after exposure to 60-70 dB of 20-4800 Hz noise for one hour. Rabbits exposed to 102-114 dB noise for 2 weeks while ingesting fatty foods had increased plasma triglycerides (that were restored to normal by injection of epinephrine).

Even immune reactions are not safe from noise effects. Daily exposure of mice for 3 hours to 120 dB of noise caused significant leukopenia followed by leukocytosis, and if the animal were injected with a virus before the noise exposure, greater susceptibility to infection was observed. Also, mice develop more polyomavirus tumors under noise stress than do non-stressed mice.

Another interesting finding is that noise affects gastric function. Rats, for example, develop more and more severe ulcers after noise exposure, as do mice and guinea pigs. Some decrease in udder function has been found following noise exposure, as evidenced by a decrease in milk production. Other organic effects, such as muscle tension, are also reported. Albers et al (1978) also report effects on behavior, for example, that long-term nighttime noise exposure decreased the performance of chimpanzees on tasks done during the day. Noise also reduced exploratory behavior and increased aggressive behavior. Albers et al (1978) then considered noise as a stressor and concluded that it is most difficult to prove stressor effects because of our inability to quantify such effects.

Borg (1978 A, B, and C) did a series of three studies on rats examining peripheral vasoconstriction in response to sound. In one study he used non-anesthetized rats, exposed to 80 dB SPL broad band noise for one millisecond up to several hours in a free field. He found that responses during continuous stimulation slowly habituated and that the time required to return to halfway normalization of arterial pulse was more than 15 minutes. He also noted that during long stimulations pulse amplitude waxed and waned, and frequently vasoconstriction lasted beyond termination of the stimulus for relatively shorter stimulus durations (up to 16 minutes or more). Thus we see that vasoconstriction slowly habituates to continuous 80 dB SPL noise, with much variability, "Endurability of the vasoconstriction may indicate that sound has a permanent influence on the cardiovascular system, (but) it is premature to speculate about harmful effects of environmental sound other than hearing loss." The second of his three part series of studies again considered vasoconstriction in unanesthetized rats, this time exposed to 4 second bursts of 80 dB SPL broad band noise with rise times of 1, 10, or 100 msec. These stimuli were found to be equally effective in inducing vasoconstriction, but longer rise times resulted in less vasoconstriction. The author believed the middle ear reflex could be a significant factor in reduced vasoconstriction with longer rise times. These results suggest that impulse type sound is probably more noxious to wildlife in their environment than continuous sound or intermittant sounds with longer rise times.

The last of Borg's series of studies investigated the effects of the pause characteristics of continuous noise on vasoconstriction in the unanesthetized rat. Specifically, the on-off response to noise was studied. He found that the offset of noise was a weak vasoconstrictive stimulus, while onset of noise after a pause did cause vasoconstriction and was independent of pause durations from 10-100 msec. With pause durations less than 10 msec., vasoconstriction was less than for longer pauses. A 2 msec. pause only occassionally caused vasoconstriction. He also noted that a 10 msec. pause caused more vasoconstriction than a 10 msec. burst of noise. Thus we see that, with regard to vasoconstriction, onset of the noise has more effect than offset. Data from Borg's series of experiments can be useful in considering the possible effects of various types of noise upon animals in the environment impacted by noise.

Observation of the behavior of Pacific mackeral, Pneumatophorus japonicus, in response to ship noise was reported by Neproshin (1978). This research was done because of the experience of commercial fishermen seeking fast swimming pelagic fish such as tuna and mackeral. They are known to react quickly and strongly to the noise made by fishing vessels and their gear by leaving the area. In this study, schools of fish were located by sonar at distances of from 200-800 meters. When a school was located, the vessel was turned so that it faced the school head on, then the vessel approached the school at 1) full; 2) medium; or 3) slow speed. Then, as soon as the school began to react to noise

from the vessel by scattering, a reading was made of the dis-tance of the school from the vessel. They found that, at slow speed there seemed to be two separate time periods during the day, and that the fish reacted more aversely at those times than at other times. They found reaction to be maximal from 12:00-2:00 p.m., it then decreased and increased again at 6:00-8:00 p.m. Reaction was about the same at medium speed. They also noted that fish reacted more in the first half of the fishing season than in the last half. Ed. note: This could be habituation to the sound stimuli. It is of considerable interest that they found that fish reacted sig-nificantly differently to approach at fast speed. They were highly reactive in the morning, less so around noon, more reactive again by 4:00-7:00 p.m. In general, fish reacted at a distance of about 50 meters, but schools were observed to react as far as 140 meters away. They also detected a corre-lation between the surface temperature of water and the re-action of the fish. It was also found that wooden ships caused less reaction by the fish than did steel hulled ships. Neproshin summarized his findings by saying that in the morn-ing, (before 8:00 a.m.) fish don't react much to noise, poss-ibly because of such factors as low light levels, and lower surface temperature of the water. Then the fish school and feed and still don't react strongly to noise. But by noon, they have fed and react strongly to the noise, light, and surface-water temperature combination. In the afternoon, they go deeper and are less reactive, then come up and by then there is less light and again react more. This study

points out rather clearly that in order to predict response of wildlife to noise we must consider many variables and their interaction with each other.

Another study by Borg (1979) investigated physiological aspects of the effects of sound on man and animals. He reported that short term effects of sound seem to depend primarily on acoustic properties of the sound and that we habituate quickly to steady signals, slowly to interrupted ones. Further, irrelevant "meaningless" sound, given over a lifetime in simulation of occupational noise exposure, did not significantly affect blood pressure, life span, or morbidity. Damage to the inner ear from such exposure was seen to be greater in hypertensive than in normo-tensive ones. He further stated that sound doesn't cause hypertension, but hypertensive individuals are more susceptible to noise induced inner ear damage. He also pointed out that individual differences were a significant influence on effects of noise. For example, variation in inner ear physiology, and blood pressure, the range of individual differences in head and ear canal resonances, middle ear impedance, and acoustic reflex response can each contribute up to 10 dB difference in net input to the ear in certain frequency ranges. He summarized his findings by stating that no permanent harmful effects of meaningless irrelevant sounds were found on non-auditory body functions of rats.

LaGardere and Sperandio (1981) investigated the effects of changes in the ambient noise level on growth of shrimp. The shrimp were raised in a sound proof box with ambient

noise levels approximately those of their natural habitat, and compared to those raised at levels about 10-15 dB higher in the frequency range of 50-500 Hz under laboratory culture conditions. Those raised in lower levels of noise had better growth rates, maintained food consumption, and were less aggressive than those raised in higher levels of noise. These results certainly suggest possible negative effects of noise on rearing of these organisms.

Changes in plasma angiotension as related to temperature and noise exposure were examined by Wright et al (1981). Angiotension II (AII) is a powerful vasoconstrictor, and rats were exposed to noise levels of 20 or 100 dB SPL white noise at temperatures of 5°, 21°, or 38°C. Loud (100 dB SPL) exposure at normal (21°C) temperature, and both temperature extremes (5° and 38°C) with low (20 dB SPL) noise exposure resulted in marked plasma AII elevations. On the other hand, the two temperature extremes (5° and 38°C) plus loud (100 dB SPL) noise exposure did not significantly affect AII levels from those seen at 20 dB SPL normal (21°C) temperature. These results suggested that separately given noise and temperature extremes stimulate production of AII and thus vasoconstriction. This in turn seems to indicate that simultaneous exposure to multiple stressors--such as noise and temperature, could significantly elevate plasma catecholamines, and could reduce renal response to B adrenergic stimuli and reduce plasma AII levels.

A recent study was made of the effects of high frequency noise on prenatal development and material plasma and

uterine catecholamine concentrations in mice by Cook et al (1982). In this experiment, mice were exposed to 112 dB temporally cycled narrow band (18-20 K Hz) noise for 12 hours, noon to midnight during either the preimplantation (day 1-6) or postimplantation (days 6-15) gestational stage. Concurrently, plasma norepinephrine (NE) and epinephrine (EPI) and uterine NE levels were determined. Catecholamines were measured on days 1 and 6 of the group exposed preimplantation and on days 6, 10, and 15 of the group exposed postimplantation, as well as on days 1, 6, 10, and 15 of the control group. Significantly lower fetal weights were found in both the pre and postimplantation groups exposed to noise. Significantly decreased maternal weight gain was also noted in those groups. Significant early entire litter resorption and more malformed fetuses were found in the group exposed postimplantation. Uterine NE was about the same for the controls and group exposed days 1-6; but exposed groups were higher on days 10 and 15. In the group exposed days 1-6, plasma NE and EPI levels were similar to control levels on day 1 but were elevated by day 6. Plasma NE was elevated on day 15 and plasma EPI elevated on day 6 in the group exposed on days 6-15 and "suggestive" ($.05 > p > .01$) NE elevation occurred in the group exposed on days 1-6. "Suggestive" overall EPI elevations occurred in both exposed groups. These results would seem to suggest that at least some of the possible effects of noise exposure might be of critical importance to the well being and viability of a species, but not obvious in any immediate way.

Peterson et al (1981, 1982A, 1982B) have done a series of studies using "realistic" sounds over long periods of time (up to about 9 mo.) to examine possible cardiovascular and behavioral effects of noise. Monkeys were used as subjects. He used moderately high but realistic levels of noise in a 9 month exposure (1981) and found elevations in blood pressure of from 23-28% in his monkeys. These effects were not reduced after the noise was turned off and were not accompanied by loss of auditory acuity. In their next study, Peterson et al (1982A) studied cardiovascular effects of noise, again in monkeys. In this study, there was an 81 day pre-exposure period where the animals were exposed only to masking noise (48 dB A noise). Then, during a 5-6.5 month per exposure period, the experimental group was exposed to sound levels from 48-90 dB A over each 24 hour period, simulating arising, going to work, work, lunch, work, going home, at home, and rest levels, with an overall LEQ_{24} of 85 dB. They found mean blood pressure (MBP) and heart rate (HR) elevated in the experimental animals due to the noise exposure. They also saw noise induced changes in the diurnal rhythm of BP and HR. Once the noise was turned off, HR dropped slightly but remained at a higher than baseline level, while blood pressure stayed at essentially the same high level reached during the final per-exposure period. These results led Peterson et al to conclude that noise effects linger beyond cessation of the noise. This series of studies is notable for at least two reasons, first its use of realistic stimuli, i.e., sounds that are actually a part of

the environment, and second, for the use of long term exposure and exposure temporal patterns. Certainly noise effects research would benefit from more realistic conditions of study like those used by Peterson et al.

One of the more important events with regard to wildlife and noise that occurred since the last literature review was brought about by concern over noise related to oil exploration, development, and production and its possibl effect upon arctic marine mammals. More specifically, the Alaska Eskimo Whaling Commission (AEWC) requested the Acoustical Society of American Coordinating Committee on Environmental Acoustics (CCEA) to consider the situation and suggest appropriate measures to insure preservation of the bowhead whale, an important cultural and economic part of Alaskan Eskimo life. A sub-committee was appointed by CCEA to consider the problem and later reported that insufficient data existed to make firm recommendations. Then, upon further request by the AEWC and the promise of funding, the CCEA set up a workshop to consider all of the various aspects of the problem of noise effects from oil related activities upon arctic marine mammals. This problem, and the workshop convened to address the problem, are illustrative of the current needs of our society with regard to detailed information about effects of noise on wildlife as well as the relative paucity of scientific information that can be found that is relevant to specific problems of this nature. Table I presents the topics covered in the workshop, divided as they were into three major areas, Biology and Bioacoustics, Arctic

TABLE I

Topics Covered at San Diego Workshop

- Biology and Bioacoustics
  - Marine Birds
  - Mammals
  - Bioacoustics
  - Behavior
  - Ethnobiology
- Arctic Environment, Engineering, and Acoustics
  - Environment
  - Systematic Engineering Approach
    - Noise sources
    - Source Measurement Requirements
    - Ambient Noise
    - Propogation Path
    - Receiver
- Conservation Policies and Programs
  - Technical Input
  - Assessment and Decision Points
  - Seismic Exploration
  - Regulation
- Permits
- Recommendations

Table I - Topics Covered at San Diego Workshop

Environment, Engineering and Acoustics, and Conservation Policies and Programs. Participants in the workshop, all of whom were invited on the basis of the expertise they were expected to be able to contribute to the problem, included native Alaskans (Eskimos), fish and wildlife biologists and related specialists, various specialist in acoustics, including bioacoustics, psychoacoustics, physical acoustics, and underwater acoustics (and perhaps more! Ed.), psychologist, physiologists, government officials at all levels of the state and federal government, many lawyers representing different aspects of the problem, and representatives of several facets

of the oil industry. The conclusions of the workshop, made in the Executive Summary of the report, are of critical importance to all who have an interest in the effects of noise on wildlife because, to a great degree, those same conclusions might be made by almost any scientific, multi-disciplinary panel asked to consider a complex situation involving possible effects of man-made noise on wildlife. Their conclusions were, "The evidence submitted at the workshop indicates that existing scientific knowledge is insufficient for a comprehensive scientific appraisal of the impact of man-made noise from projected petroleum-related activity on Arctic marine wildlife. Furthermore, based on reported direct observations and other scientific data, there is a significant likelihood of possible adverse effects on certain marine birds, ringed and bearded seals, and bowhead whales. Some concern was also expressed about other animals, including the grey and beluga whales, walrus, polar bear, spotted seals, fish, and lower animals in the food chain. They went on to say that "appraisal of the expected noise impact with any degree of certainty requires much additional data on noise sources, noise propogation in the Arctic environment, general ambient noise conditions, physical environmental factors, and animal response to such noise." The report has this to say about the possible effects of noise on bowhead and beluga whales. It is not known whether or not the populations of bowhead and beluga whales will be adversely affected by man-made noise and vibration resulting from oil ex-

ploration and production activities. It is already evident that at certain times, or under certain conditions, they react differently to noise stimuli. Bowheads appear more wary of noise during spring as compared to their response during autumn migration. Feeding beluga whales are less easily displaced by boat traffic than when they are not feeding. Information on behavioral responses to sound may not necessarily constitute evidence that the population, or for that matter, individuals, exhibiting a response will suffer permanent damage." Jack W. Lentfer, a wildlife biologist with the Alaska Department of Fish and Game, says of the polar bear and noise, "The greatest potential threat from acoustic disturbance is to denning bears." He pointed out that polar bears have a relatively low reproductive rate--.46 young/adult female/year, and that denning is essential in the Arctic for cub survival. Therefore, any threat to the denning mother, or disturbance that disturbs denning, constitutes a serious threat to cub survival and therefore to the species. John J. Burns, another Alaskan wildlife authority with the Alaska Department of Fish and Game, reported on the biology of seals. With regard to noise, Burns said, "Ringed seals appear susceptible to man-made acoustic disturbances in the fast ice zone. Bearded seals seem to show little response to continuous, low-level sounds. However, no experimentally rigorous experiments of this nature have been conducted on either species." A preliminary report of studies made of the bowhead whale was made by Dr. Marilyn Dahlhein from the National Marine Fisheries

Service, Seattle, Washington. Their studies included observation of the behavior of bowhead whales in response to noise from their research vehicles, both aerial and vessel surveys. The aerial survey used two Sikorsky HH-52A helicopters while the survey vessel was the USCGC Polar Sea. Reaction of the bowheads to noise by the helicopters flying at either 152 m. or 228 m. altitude was not significantly different. Whales displayed an escape reaction in only 11 of 160 encounters. No data were presented regarding response to vessel noise. Possibly one of the more important outcomes from the San Diego workshop was a recommended scientific research plan that gave a detailed list of research needs by priority for a better future knowledge and understanding of effects of noise on arctic marine wildlife. One recommendation was for direct observation of wildlife both in their natural habitat and in the laboratory. These efforts in the natural surround-ing would include animal census and distribution, seasonal activities related to species viability such as courtship, mating, denning, etc. Experimental efforts would involve controlled alteration of the environment and observation of behavior under altered conditions. Another recommendation was for biological study of food chain ecology and the response of elements of the food chain to sound. Recommendation was also made for bioacoustic studies. The hearing abilities of specific species need to be known--not only absolute, but masked threshold data. Stressor effects of noise were also given a high priority for research.

From the San Diego workshop several things became apparent. There is a critical lack of information regarding many aspects of noise and its effects upon wildlife. This absence of scientific data is such that for many, if not most, species we are unable to predict the possible effects from noise. Much of the necessary information about the animals themselves is missing, such as frequency range of hearing, threshold data, as well as physiological data regarding their response to noise at various times and under different conditions.

The literature review made at the last Noise as a Public Health conference (Fletcher, 1980) concluded with several recommendations for future research and study. The first suggested a "study of individual species, one by one, as individual animals and in social groups (herds, flocks, etc); such studies should examine the acoustic nature (frequency, intensity, temporal pattern, etc.) of critical events of the animal (mating, territoriality, alarm, nurture, etc.). No evidence can be found that this recommendation has been followed, and the need for the work suggested is as pressing today as it was in 1978 when the recommendation was made. This fact was noted at the San Diego Workshop on the Interaction Between Man-Made Noise and Vibration and Arctic Marine Wildlife and similar recommendations were made. The second recommendation from the last noise and wildlife review suggested that more complete knowledge of environmental sound and of animal hearing sensitivity is required. It

still is. As before, noise analyses that are presently being done cover only a limited frequency range and this could not give information that might be relevant to many animals. The recommendation called for data on the effects of noise on a declining animal population regardless of why the population is declining. This information is needed today. The next research need outlined in the previous literature review recommended examination of the combined stressor effects of noise and other stresses on animals. Some laboratory studies of multiple stressors, with noise one of the stressors, have been done, (Gunther et al 1978, Wright et al 1981). The fifth recommendation was for both acute and chronic studies of noise effects. Certainly the series of studies by Peterson et al 1981, 1982A, 1982B, provide needed information about certain effects of long-term exposure. Another recommendation indicated a need for field as well as laboratory studies. Other than the study of mackeral by Neproshin (1978), no field studies have been done. The need for field studies is just as criticcal now as it was at our last conference.

Finally, a need for studies of sound propogation in the field was suggested. These studies are also needed today. This presentation of the research needs that were voiced at our last conference compared to the research that has been done since that time shows that essentially all of the needs of that time still exist today, and the gaps in knowledge necessary to deal effectively with possible effects of noise on Arctic marine wildlife, as outlined in the report from

the San Diego Workshop (1981) have not yet been filled in. We still are inadequately informed about most facets of the effects of noise on wildlife and other animals.

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SOME CARDIOVASCULAR AND BEHAVIORAL EFFECTS OF NOISE IN MONKEYS.

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INTRODUCTION

Although extensively investigated, the relationship between protracted noise exposure and the cardiovascular system has yet to be satisfactorily defined (e g , Thompson et al , 1981) As an experimental strategy for increasing our understanding of this relationship, animal model research offers two distinct advantages It allows a greater degree of control to be exercised than is practical in human epidemiologic studies and it allows subjects to be observed over longer periods than is practical in human laboratory studies

Historically, results from the majority of animal studies have supported the predominantly positive findings derived from human epidemiologic studies (e g , Algers et al 1978) Yet, over the past five years well-designed experiments have yielded both positive and negative results (Borg and Jarplid 1981, Borg and Moller, 1978, Kraft Schreyer and Angelakos, 1979; Turkkan, 1983, Blotnik, 1982, and Ising, 1981)

The primary aim of the present study was to determine whether or not protracted exposure to moderately intense levels of noise can significantly elevate blood pressure in non human primates Secondary issues dealt with in this study involve subtle post exposure after effects, hemodynamics underlying blood pressure changes, and conditions that alter the magnitude of noise effects

MATERIAL AND METHODS

Detailed descriptions of our procedures can be found in several previous reports (e.g., Peterson 1983, 1980, Peterson et al, 1981). They will only be summarized here.

SUBJECTS: Female macaque monkeys (M mulatta, M fascicularus), 5-7 years old and weighing 3.5-4.5 kgs were used. *In general, two animals* served as high noise experimentals and two served as low noise controls. All animals were habituated to experimental conditions, *including chair restraint, for about* seven months prior to entering the experiment proper. After surgical implantation of blood pressure cannulae and other sensors, animals were placed in sound attenuating, isolation chambers.

PROTOCOL: Our study encompassed five experimental phases. Protocols varied somewhat from phase to phase. Nevertheless, the basic design consisted of pre, per and post exposure periods. Elaborations on this theme have been described in the reports cited above.

During the pre exposure periods, which lasted from 0.5 to 3 months, all animals were subjected to low and constant noise conditions. Levels ranged from 47 to 53 dB (A).

During the per exposure periods, which lasted 3 to 9 months, controls remained under these low noise conditions while experimentals were subjected to high noise conditions created by six recorded noise episodes. In the first two experiments, stimulus level, content and timing had been adjusted to emulate an exposure pattern which could be experienced by workers in a noisy industry over the course of an entire day. *In the last three experiments, only* that episode, "workplace noise", which earlier had proven to be most effective in altering blood pressure was *retained*. Across all episodes and forms of stimulus, animals were exposed to daily average energy levels (L_{eq24}) ranging from 85 to 90 dB.

During post exposure periods, which lasted 0.5 to 4 months all animals were subjected to low noise conditions.

ENVIRONMENT: In view of the strong influence they can exert on cardiovascular function, environmental factors, including temperature, *relative humidity, illumination*, fumes, external noise and human contact were either minimized or maintained within narrow limits, as appropriate, and carefully monitored.

DATA ACQUISITION: Output from various sensors associated with each animal were monitored sequentially. In all experiments but the first, dwell time was eight seconds every two minutes. Thirty, 8-second measurement samples were thus acquired from each animal each hour. Only the mean, standard deviation and number of hourly measurements were summarized and saved on disc for off-line analyses. Statements of variability and population mean estimates described below are based on the standard deviations derived in this way. Cardiovascular parameters including systolic, diastolic, and mean blood pressure, pulse pressure, heart rate, heart rate timing consistency, heart rate distribution, and rate pressure product were all derived from the pressure pulse waveform. In one study, stroke volume, cardiac output and total peripheral resistance were derived from the aortic blood flow waveform. Other variables including sound level, temperature and movement were also continually monitored. Over the course of each experiment 10^5 to 10^6 measurement samples were obtained from each animal and for each variable.

RESULTS

OVERALL: Table 1 summarizes the results for mean arterial pressure (MAP) from four experimental phases of the University of Miami project. As can be seen, MAP for animals under low noise conditions (excluding post noise exposure periods) averaged 76.2 torr. MAP for animals exposed to high noise levels averaged 99.8 torr. Within experimental animals, pre to per exposure period increases averaged 27.5%. Although there have been wide individual

differences in our studies, no animal chronically exposed to noise has failed to manifest an increase in MAP from baseline levels. Further, during the per exposure periods MAP for experimentals averaged 33% higher than that for simultaneously run controls. Interrupted time series analyses, applied to intra-subject data and repeated measures analyses of variance, applied to inter-group data from individual experiments have revealed highly significant differences related to high noise conditions.

TABLE I
RESULTS FROM UNIVERSITY OF MIAMI PROJECT
MEAN ARTERIAL PRESSURE (TORR)

	Pre-Exposure		Per-Exposure	Δ	Δ %
		Phase I[a]			
Experimental	79 ± 3.4[b]		101 ± 3.9	22	29(e-e)
Control		82 ± 3.0		19	23(e-c)
		Phase II			
Experimental	74 ± 2.6		102 ± 3.0	28	38
Control	70 ± 2.7		70 ± 2.8	32	46
		Phase III			
Experimental	85 ± 2.4		95 ± 2.5[d]	10	12
Control[c]		76 ± 2.5			
		Phase IV			
Experimental	77 ± 2.4		101 ± 2.3[f]	24	31
Control[e]		73 ± 2.2		28	38
$\bar{X}$, Low Noise		76.2		$\bar{X}_{e-e}$; 27.5%, Range; 12 38	
$\bar{X}$, High Noise		99.8		$\bar{X}_{e-c}$; 33.0%, Range; 23 46	

a. M. Mulatta; b. 0.95 confidence limits about the mean; c. pooled from our other experiments, N = 12; d. includes 4 and 8 hour daily exposures; e. controls entered experiment at onset of Pre-exposure period; f. includes interdigitated rest periods.

DIURNAL RHYTHM: In addition to these gross changes, however, more subtle ones have occurred. For example, in experimental phases I and II we found that during the per exposure period the diurnal rhythm of MAP was so altered that it became highly correlated with hourly variations in stimulus level ($r = 0.82$, $p < .001$ in Phase I).

In phase III only the work place episode was presented, for either 4 or 8 hours per day, across a total of seven noise-exposure sessions. Diurnal rhythm of MAP for both exposed animals in this phase was modified not only over exposure sessions but over randomly interpolated, low-noise rest sessions and over a large segment of the four month post exposure period as well. Such results point to the strong influence exerted on blood pressure regulation by the workplace noise. To illustrate, Figure 1A displays

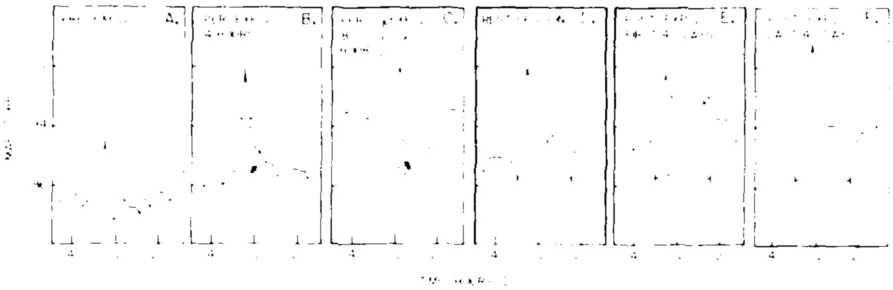

Fig. 1 Phase III: Diurnal rhythm of mean arterial pressure (MAP) for experimental animals. Several epochs are shown.

the averaged, hourly trend of MAP for the two exposed animals during the pre exposure period. The pattern was characterized by a mid day concavity coupled with a large peak associated with routine feeding, cleaning and gentling activities. Both the activities and the elevation in MAP engendered by them were common to *all experimental periods and all animals*. Figures 1B and C show the diurnal rhythm during the 4 and 8 hour exposure sessions, respectively. MAP was clearly elevated during exposure hours and in both cases it was closely related to the pattern of work place noise intensity (See dashed line). Figures 1D, E and F show the diurnal rhythms during other low noise conditions. A lack of short term (ie $\bar{X}$ = 7 days) recovery during the rest sessions interleaved among exposure sessions is demonstrated in Figure D. Although the curve here was a composite of post 4 hour and post 8 hour exposure sessions, it obviously resembled the exposure patterns far more than it resembled the baseline one. Figure E demonstrates the lack of longer term (40 days) recovery. Specifically, it shows retention of the diurnal pattern established during the final 8 hour exposure sessions. By contrast, Figure F may demonstrate partial adaptation of the changes imposed by this exposure and a reversion to baseline, even though MAP was still significantly elevated from pre exposure values (85 vs 95 torr, $p < .05$).

HEMODYNAMICS: The long term hemodynamic changes associated with the blood pressure changes we uniformly observed in exposed animals are of considerable clinical interest. In a

fourth experiment we measured cardiac output (CO) stroke volume (SV) and total peripheral resistance (TPR), in addition to MAP and heart rate (HR), for more than 14 months in an experimental animal, "Teri" During this time we also measured these parameters for one to two months in two control animals. Control animal values for CO were 11% higher than those for Teri under low noise conditions (855 vs. 772 ml/min).

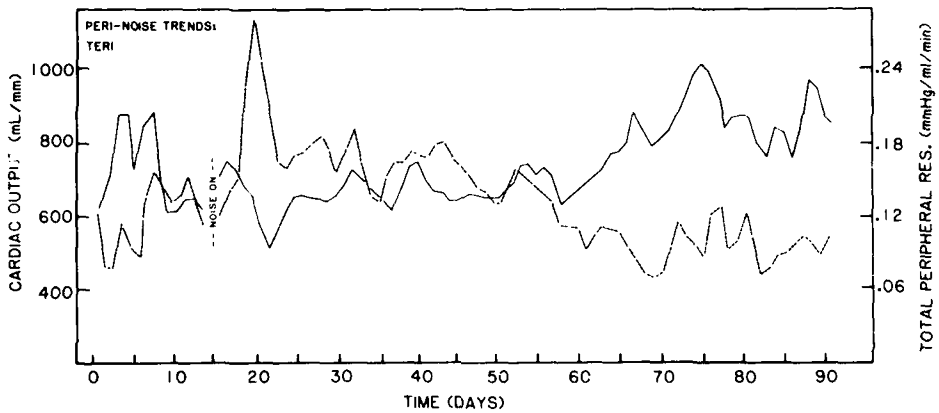

Fig. 2 - Phase IV. Peri noise (90 days) trends of cardiac output (CO dashed lines) and total peripheral resistance (TPR, solid lines) for experimental animal, "Teri"

Figure 2 indicates peri noise trends of TPR and CO for Teri. After an initial period of instability, the surgically implanted flow probe became properly seated around Teri's ascending aorta and thereafter it provided a very clean flow signal. Reliable data from this time indicates that during the last 15 days of the pre exposure period, CO tended to increase while TPR tended to decrease slightly. With onset of the workplace noise, 8 hrs per day, both parameters manifested phasic changes. For a few days both rose slightly. This was followed by a sharp *increase* in CO, accompanied by a sharp *decrease* in TPR. Both parameters briefly stabilized and then over the next 60 days CO fell monotonically and TPR rose monotonically.

All told this animal was monitored for 467 days, including a baseline, three exposure and three inter digitated post exposure periods. Long term trends for five of the cardiovascular parameters sampled are shown in Figure 3. Note first that the thorocotomy surgery required to

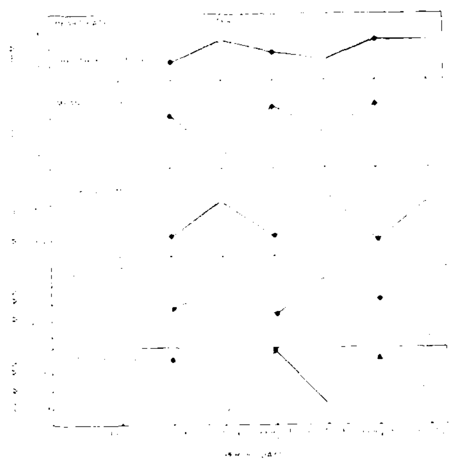

Fig 3 - Phase IV: Long-term trends of five cardiovascular parameters measured in experimental animal "Teri"

implant the flow sensor was not a benign procedure for this animal. This was suggested by the 13 torr increase in MAP after surgery. This, in turn, may imply some degree of surgical recovery-noise effect interaction. Be that as it may, within each of three exposure periods MAP rose significantly over both pre-surgery and post surgery levels. Typically, it fell repeatedly during the interleaved post-exposure periods. The overall trend therefore took on a saw-toothed appearance. As can be seen, long term correlation between MAP and heart rate was low, between MAP and SV or CO high, but negative, and between MAP and TPR highly positive.

HEART RATE DISTRIBUTION: At the Freiburg Congress, Ising (1978, personal communcation) shared the results from a pilot study in which he determined, in a single pig, the distribution of the differences in adjacent R to R wave intervals under both quiet and noisy conditions (Leq_{12} = 90dB). Figure 4 is adapted from information provided then by Ising. It shows the two distributions, based on a sample of 12,000 beats. Note that the differences were distributed normally in this animal under quiet conditions while they appeared to be distributed with negative skew under noisy conditions.

In our experience, HR *per se* has not been consistently altered by noise presentation but given impetus by Ising's preliminary data, we attempted to demonstrate that more subtle

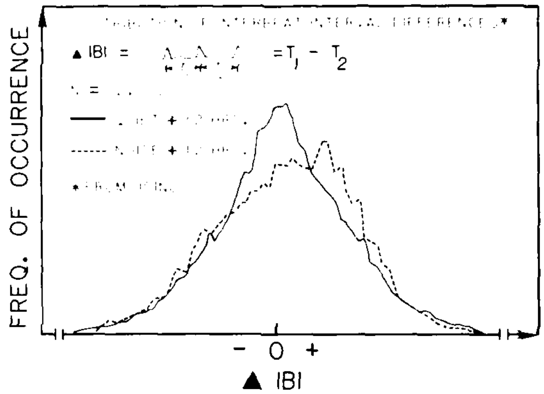

Fig 4 - Distribution of differences in inter-beat intervals under conditions of quiet and noise. Adapted from Ising, 1978.

aspects of cardiac pacing regulation can be affected by noise We have already reported on some of the ways beat-by-beat cardiac pacing can be influenced (c.f. Peterson et. al, 1983) Subsequent studies have revealed that distinctive changes can also occur in the distribution of HR values. The long-term results from phase IV are illustrated in Figure 5. HR and HR distribution were compared in two experimental and two simultaneously run control animals during the three exposure periods shown in Figure 3. As can be seen, HR was significantly

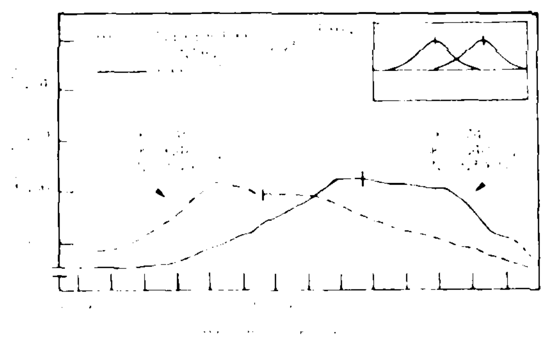

Fig. 5 - Phase IV Heart rate distribution for control and experimental animals across three exposure periods 10 beat blocks

higher in experimental animals during this time than it was in control animals (174 ± 5.6 vs 145 5.1 ± BPM, p < .05) The inset to Figure 5 portrays one reasonable hypothesis regarding

the relation between the two HR distributions. In view of the large number of observations ($N > 10^6$), it might have taken the form of two overlapping Gaussian functions. In reality however, the two curves followed a form suggested by Ising's data, the low noise animals displayed a positively skewed distribution while the high noise animals displayed a negatively skewed one (+0.46 vs. -0.40, respectively). This is shown in main portion of Figure 5.

STIMULUS CONTROL, A PILOT STUDY: Throughout the four experiments discussed above, exposed animals were unable to control stimulus *timing* or *level*. Since lack of control in humans is said to exacerbate noise effects (c.f. Cohen, 1980), this feature of our protocol may, at least partially, account for the robust changes in blood pressure we consistently observed. To test this hypothesis in a fifth experiment, we provided an exposed animal with a simple instrumental means (a single lever-press) for substantially lowering stimulus levels for *one* minute.

After a 30-day baseline and training period, the subject, (Fondy),was presented, 8 hours per day, with the workplace noise set at 77 to 112dB peak SPL. Average sound energy level, Leq_{24} was 84.5dB. Average energy during exposure Leq_8 was 89.5dB. This was similar to previously used exposure levels. Attenuation achieved with each lever press was adjusted to 10, 15 or 20dB. During the first 22 days stimulus levels were set to 102dB, attenuation to 15dB. Thereafter, presentation of level-attenuation combinations was counter balanced.

This animal rather quickly established stimulus oriented response strategies. That is, she generally reacted more vigorously and rapidly under those circumstances when the noise was more intense and/or when attenuation was greater. As an example, response latency, defined as the time between onset of maximum noise and the first lever press, was 61% shorter for higher noise levels than lower ones (19 ± 3.7 vs. 49 ± 13.5 seconds). It was 71% shorter with greater than with less attenuation (15 ± 3.1 vs. 52 ± 14.0 seconds).

Figure 6 presents average latencies across the range of stimulus levels and attenuation used. Since latency was shorter at the same stimulus level when stimulus attentuation was greater, total time at the reduced level was also *increased* and exposure thereby minimized.

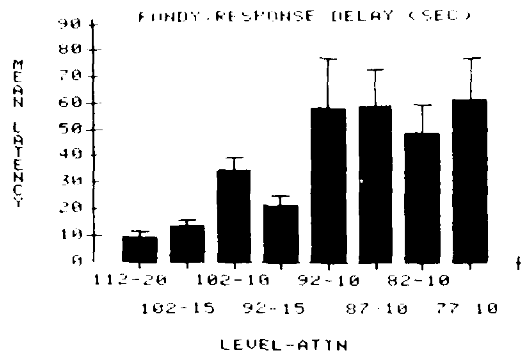

Fig. 6 - Phase V Lever press latencies for experimental animal "Fondy", over a range of stimulus level and attenuation Capped bars represent 95% confidence limits

The remarkable orderliness of this animal's responses can be further exemplified by the changes in the frequency distribution of latencies that accompanied changing stimulus conditions. Figure 7 indicates the shift from shorter (0 to 19 seconds) to longer (20 to < 60 seconds) latencies both as maximum stimulus level and attenuation were decreased

The analysis of the ratio of latencies less than 10 seconds to those greater than 60 seconds and of latencies greater than 100 seconds, shown in Figure 8, clearly demonstrates this shift also but from another perspective

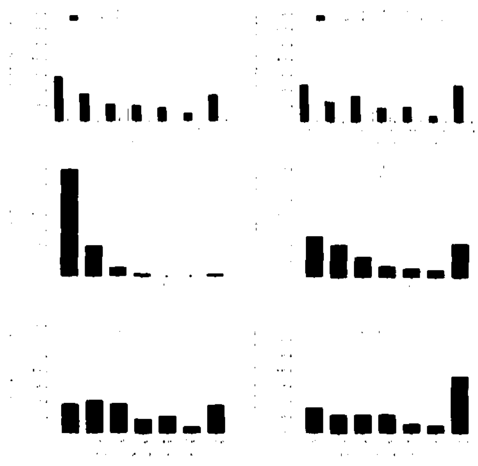

Fig. 7 - Phase V Frequency distribution of latencies across stimulus conditions Ten second blocks

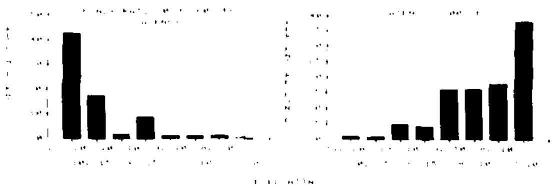

Fig. 8 - Phase V: Latency shifts across stimulus conditions. (a) Ratio of short to long latencies. (b) Latencies greater than 100 second.

In addition to these behavioral observations, blood pressure was continually monitored before and during 45 days' exposure. From the pre to the per exposure period, MAP for this animal rose 6.6 torr (78 ± 2.3 vs. 85 ± 2.4 torr). Although it was significant ($p < .05$), the change was considerably smaller than had been manifested by other animals similarly exposed in our studies.

CONCLUSIONS

The results of five long term experiments strongly suggest that the fundamental issue we addressed in this work may be answered in the affirmative. That is, under certain well controlled conditions, chronic exposure to moderately intense noise *can produce sustained* blood *pressure elevations* in non human primates. Beyond this, however, we addressed other important issues which bear on the case for a causal relationship between noise and cardiovascular function.

AFTER-EFFECTS AND ADAPTATION: In all our experiments noise related changes in the level and diurnal rhythm of blood pressure lingered to some degree beyond the time of actual exposure. Although they are long lasting the modifications so imposed appear now *not* to be *permanent*. *Under our experimental* conditions more subtle aspects of the changes, particularly patterns of diurnal rhythm, tend to regress toward baseline after a few months post exposure, *even* though *grosser changes* such as *increased* blood pressure, continue to be manifested. The possibility therefore arises that the various after effects may have different and somewhat independent schedules.

HEMODYNAMICS: Andren (1982) recently reported acutely decreased cardiac output and

increased total peripheral resistance in humans exposed to a steady 95 dB(A) noise. The highly phasic, short term hemodynamic responses observed in Teri contrast with Andren's findings. The long term trends for this animal, nevertheless, are in substantial agreement with them. The present findings additionally suggest that over the long run, noise induced blood pressure elevations are maintained more by alterations of the vascular periphery and less by alterations of the inotropic or chronotropic properties of the heart. This conclusion seems reasonable because neither heart rate nor stroke volume based increases in cardiac output were observed in the presence of noise. The importance of other factors such as disruption of the water salt balance has not beenassessedin our studies.

ENHANCING CONDITIONS: Considerable evidence bearing on instrumental control of noxious events or conditions presently exists. In keeping with a large group of earlier findings, we observed in Phase V that an animal provided with a simple and reliable means for ameliorating noise exposure, showed blood pressure elevations in the presence of noise considerably smaller than those of similarly exposed animals that did not have such control. It may be then, that passive reception of the noise contributed to the large increases in blood pressure we previously observed. The stimulus related strategies devised by this animal to minimize exposure were also noteworthy and they may provide a model for investigating such concepts as "annoyance" or "noisiness" in primates.

All in all, the experimental model developed for this project has proven useful in defining a few of the ways in which noise influences the behaviour of non auditory systems. Recent contradictory findings from other laboratories may be due to methodological or species differences. They may also be due to an interaction of these differences with the inherent complexity of noise induced health effects.

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THE NON-AUDITORY EFFECTS OF NOISE ON THE BABOON.

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INTRODUCTION

There is increasing concern that environmental noise has adverse effects on health beyond those directly associated with the auditory nervous system, such as various forms of cardiovascular disease, reproductive dysfunction, and changes in immune response (Hattis and Richardson, 1980; Welch, 1973). The ubiquity of moderate to high environmental noise levels, along with the high prevalence of cardiovascular disease in modern society, argues for special attention to the relationship between noise and cardiovascular health. In the studies of the cardiovascular effects of industrial noise on humans, questions of design have arisen, focusing on the lack of controls for non-workplace noise levels and on the confounding of noise with other stimuli such as vibration, heat, poor ventilation, or even the anxiety of working with heavy machinery (Kryter, 1972; Thompson, 1981).

Numerous experimental studies have been conducted with animals to control for such problems. Among non-human primates, rhesus monkeys (Peterson, Augenstein, Tanis, and Augenstein, 1981) have shown significant elevations in blood pressure when exposed to noise levels of 79-100 dBA.

Peterson et al. (1981) found that when rhesus monkeys were exposed to a sequence of noise episodes that approximated the daily pattern of noise to which an industrial worker might be exposed (LEQ_{24}=24-85 dBA), marked elevations in blood pressure were found (29% increase) within a month of noise exposure, which then stabilized. These cardiovascular changes occurred in the absence of any detectable changes in the functioning of the auditory system as assessed by brainstem evoked response audiometry. Thus, certain aspects of cardiovascular function may be altered after relatively long periods of exposure to a realistic noise sequence, the alterations being "extra-auditory" in that they occur in the absence of any known effect upon the auditory system. In the present experiment, another species of non-human primates was exposed to 8-hr daily industrial noise episodes at intensities that predispose organisms to such "extra-auditory" changes.

MATERIAL AND METHODS

General Procedure. Operant conditioning methods were used to train male baboons to perform a standard auditory psychophysical procedure (Hienz, Turkkan, and Harris, 1982; Pfingst, Hienz, and Miller, 1975) in order to obtain accurate estimates of their baseline hearing sensitivity. Animals were then surgically prepared with catheters for blood pressure and heart rate monitoring, and remained in resting conditions until baseline cardiovascular levels stabilized. Following stabilization, animals were exposed to the 8-hr/day industrial noise sequence for periods ranging from 4 days to 4 months. Noise was then terminated, with cardiovascular levels monitored for an additional two weeks. To redetermine the integrity of the auditory system, auditory threshold testing was repeated at octave frequencies ranging from 500 Hz to 16 kHz. Throughout all experimental stages, plasma was collected for determinations of plasma catecholamine levels as an index of sympathetic nervous activity prior to and during noise exposure.

Four sub-adult male baboons (*Papio cynocephalus*) weighing approximately 20 kg were used. Subjects were maintained on a restricted 22-hr feeding schedule during auditory threshold testing. During noise exposure, they were fed twice a day, 6-7 hours apart. Baboons were housed separately in specially designed acoustic chambers with inside dimensions of 1 m X 1.3 m X 1.7 m. Total attenuation between chambers ranged from 60 dB at 250 Hz to >100 dB at 2 kHz and above. During auditory threshold testing animals responded on an intelligence panel within each chamber,

which contained a response lever, a cue light, and a tube feeder for delivery of food pellets. Additionally, a wide-range acoustic driver located 80.5 cm above ear level of the subjects was used to deliver pure tones during auditory threshold testing, and to deliver industrial noise during the noise exposure sequence. The industrial noise employed was the "pile driver" sequence of Peterson et al. (1981), played from a reel-to-reel tape recorder. The noise sequence consisted of pile-driver impacts occurring about 82 times per minute in the presence of background construction noise. Predominant energy peaks of the impact noise occurred at 500-700 Hz. Noise intensity is expressed as the A-weighted average energy equivalent level. Exposure intensities examined were 83, 93, and 97 dBA. The tape-recorded noise sequence was electronically filtered to match the spectral characteristics of the noise sequence as employed in the Peterson et al. (1981) study.

To measure continuous arterial pressure, each baboon was surgically prepared with a silicone-coated polyvinyl catheter implanted in the femoral artery and advanced to just above the iliac bifurcation. The distal end of the catheter was tunnelled under the skin, exited in the interscapular region, and then connected to a Statham strain gage transducer. The blood pressure waveform was displayed on a polygraph, and was also converted to digital units by a microprocessor that scanned the waveform at 333 samples per second. Systolic and diastolic blood pressure, and interbeat interval (used as the heart rate measure) were obtained at each heart beat.

Following initial surgery, each animal was exposed to a constant masking (white) noise at 53 dBA to establish a pre-exposure baseline of cardiovascular measures. Typically two or three weeks were required to establish a blood pressure baseline within 5-10 mm Hg of daily variability that showed no systematic trends. Following baseline stability, animals were exposed to the noise sequence. Baboon MA received 17 weeks of exposure to the 8-hr daily noise episode at 83 dBA, 2 weeks of post-noise recovery, and 1 week of behavioral testing for hearing loss. Due to a lack of clear blood pressure elevations during noise exposure at 83 dBA, this animal was reestablished at baseline cardiovascular levels and then exposed to 1 week of daily 8-hr noise episodes at 93 dBA, followed by 4 weeks of exposure at 97 dBA, 1 week of post-noise recovery, and 2 weeks of behavioral hearing retests. Baboons SI and MI were exposed to the 8-hr daily noise episodes at 97 dBA, while Baboon AL served as a no-noise control and received the constant 53 dBA masking noise for three months. Only data from the acute effects of noise exposure are available for Baboon SI.

RESULTS

Acute Effects of Noise. Pronounced cardiovascular effects were observed on the first day of initial exposure to noise at 97 dBA for Baboons MI and SI. Both animals showed elevated blood pressures and increased heart rates within the first 10 minutes of noise exposure. Systolic and

diastolic pressure changes peaked at about 50 and 30 mm Hg, respectively, within the first hour following noise onset. Heart rate increases likewise peaked during the first hour after noise onset, with interbeat interval (IBI) values reduced by 42-56 msec. Overall duration of these acute effects of noise onset was about 4 hours for both animals. Baboon MA, whose initial noise exposure was at 83 dBA, showed no discernible effects during day 1 of noise, but cardiovascular increases became prominent with further exposure. A comparison of the 3 exposure intensities this animal received revealed that magnitude of blood pressure response was directly related to noise intensity.

For the two animals whose initial exposure to noise was at 97 dBA (MI and SI), a minute-by-minute analysis of cardiovascular changes was performed for the 4 minutes prior to and following noise onset on the first day of exposure. Both animals showed immediate increases in systolic and diastolic pressures, as well as heart rate, following noise onset (Figure 1). These elevations occurred within the first minute after noise and continued to rise thereafter. Systolic and diastolic pressures increased by approximately 22 and 12 mm Hg, respectively, while IBI decreased by about 350 msec, representing a heart rate increase of 54 beats/min. Figure 2 shows minute-by-minute cardiovascular changes averaged over consecutive weeks of exposure for Baboon MA's first exposure to noise at 83 dBA. Diastolic blood pressure increased immediately after noise onset in the early weeks of exposure, and then gradually diminished over the 17-wk noise exposure period, suggesting habituation to the acute effects of noise over the course of the experiment. Habituation to noise onset effects was also evident at the 97 dBA noise intensity in this subject and in Baboon MI. First indications of habituation appeared after about 5-6 weeks of noise exposure, suggesting a possibly shorter time

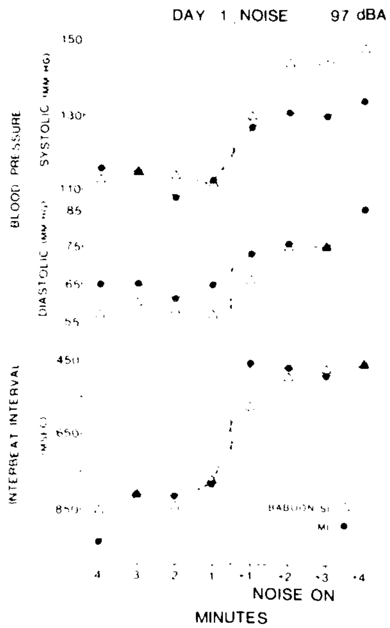

Fig. 1 - First exposure to industrial noise at 97 dBA; systolic and diastolic pressure and interbeat interval for two baboon subjects at the time of noise onset. Each data point is a one-minute mean. In this and subsequent figures, the interbeat interval axis is inverted so that rising functions indicate rising heart rates, and vice-versa.

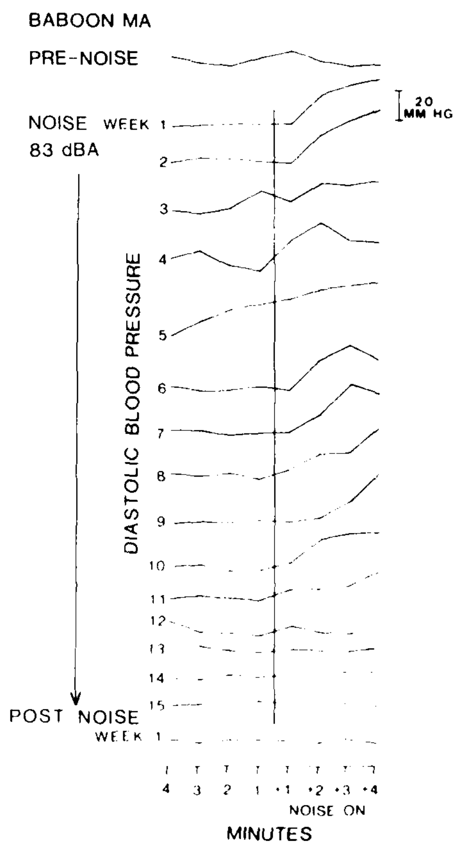

Fig. 2 - Habituation to noise at 83 dBA, showing successive minutes of diastolic blood pressure for Baboon MA. Weekly functions are an average of daily one-minute means. Pre-noise (top) and post-noise (bottom) are also shown. One cm represents 20 mm Hg.

course of habituation at this higher noise level. Acute changes in interbeat interval did not habituate as quickly as did changes in blood pressure.

Chronic Effects of Noise. Although transient increases in blood pressure and heart rate were obtained early in the noise-exposure history of each subject, the chronic effect of continued noise exposure was to lower blood pressure and heart rate. Figure 3 demonstrates this lowering for two

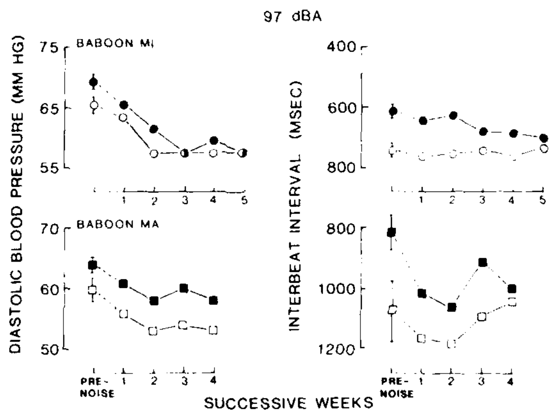

Fig. 3 - Successive weeks of exposure to noise at 97 dBA, showing weekly averages of diastolic pressure and interbeat interval for two baboons. Close and open data points represent, respectively, noise-on and post-noise periods, both 8 hrs duration.

subjects exposed to noise at 97 dBA for 4-5 weeks. Within the first week of noise exposure, diastolic blood pressure during noise (closed data points) dropped 2-5 mm Hg, with the largest drops (6 and 12 mm Hg) occurring after three weeks. The largest heart rate decreases were about 10 BPM (80-100 msec decreases in IBI). In the 8 hours following daily noise offset (open data points), decreases were also apparent in diastolic pressures, showing an overall drop of about 5-12 mm Hg. Blood pressures and heart rates were similarly reduced in Baboon MA who received noise exposure at 83 dBA.

High performance liquid chromatography assays of plasma catecholamines for Baboon MA revealed that in the first week of noise exposure epinephrine and norepinephrine levels showed little change. After a month of noise exposure, however, catecholamine levels were suppressed below baseline, with norepinephrine and epinephrine values falling by 221 and 44 pg/ml, respectively, representing decreases of 55-65%. Decreases in the cardiovascular parameters were also apparent at this time, with systolic pressure decreased by 15%, and diastolic pressure and heart rate decreased by 30%.

A closer examination of within-day cardiovascular trends is shown in Figure 4, which plots weekly averages of hourly diastolic blood pressures for 24-hr periods, with black bars depicting noise-exposure periods. The diastolic pressure curve for the final pre-noise week (dashed lines) is superimposed on each noise function for comparison. After noise exposure at 83 dBA, decreases in diastolic blood pressure were initially apparent only during and immediately preceding the noise-on period. After 12 weeks, blood pressure was lowered for approximately 16 hours of the day, again in the period during and immediately preceding noise. After 16 weeks of noise exposure, pressures were lowered throughout the day relative to the pre-noise levels. By the second week after noise termination, blood pressures returned to baseline (pre-noise) levels in the late evening and early morning hours, and were approaching baseline levels during the former noise-exposure hours. Heart rates (not shown) followed similar daily patterns. Overall decreases in blood pressure also occurred at 97 dBA for Baboons MA and MI (not shown), with both of these animals showing pressure decreases after about 4 weeks of noise exposure, a shorter time period than that required to produce the overall pressure

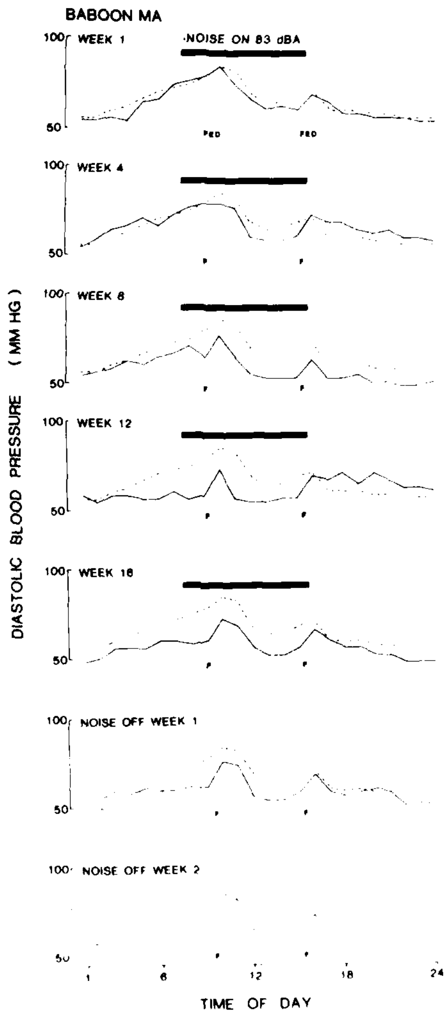

Fig. 4 - Diastolic blood pressure as a function of time of day during selected stages of the 83 dBA noise exposure protocol for Baboon MA. The black bar above each panel depicts the noise-on period; feeding occurred at "F". Dashed-line functions represent the final pre-noise week, and are superimposed on each panel for comparison. Each function is composed of hourly means, averaged over 7 days.

lowering at 83 dBA. Baboon AL, who received only masking noise at 53 dBA did not exhibit lowered blood pressures or heart rates over a 3 month period.

The data in Figure 4 and from other subjects suggested that the cardiovascular effects of noise may have been obscured by the morning meal, which in the pre-noise curve can be seen to generate blood pressure (and heart rate) increases. Accordingly, in the fifth week of noise exposure for Baboon MI, the routine daily meal was given at 4 PM, three hours after noise offset. The result of moving the feeding hour to the afternoon was to eliminate the AM blood pressure and heart rate rise, and indeed to produce a sight lowering (4 mm Hg diastolic) over the initial 2 hours of noise onset.

Pure-tone behavioral thresholds were obtained at the octave frequencies from 250 Hz to 16.0 kHz for Baboon MA after his 16-week exposure at 83 dBA, and for Baboons MA and SI following their 97 dBA exposure. All thresholds approximated normal pre-exposure threshold levels, indicating no permanent effects of the noise exposures on basic auditory acuity.

CONCLUSIONS

The results of the present study indicate that exposure to realistic levels of industrial noise produce acute increases in pressure and heart rate within the first minute after noise onset. The acute noise exposure effects appeared to be related to the magnitude of the noise intensity, being observed during the first day at 97 dBA, not present on day 1 at 83 dBA, and appearing gradually over the first week at 83 dBA. Further, a dose-effect relationship was demonstrated between noise intensity and diastolic pressure increase for the first week at 83, 93, and 97 dBA. The

time course of habituation of acute cardiovascular effects appeared to be inversely related to noise intensity. These data lend support to the suggestions of others (e.g., Borg and Moller, 1978) that organisms may habituate to at least some of the long-term effects of noise exposure.

The chronic noise-induced decreases in blood pressure, heart rate, and catecholamines have little parallel in the literature, where the vast majority of both human and animal studies have shown either no change (e.g., Malchaire and Mullier, 1979; Borg and Moller, 1978) or increases in cardiovascular and hormonal levels (Hattis and Richardson, 1980). It has been suggested, however, that younger humans may respond to chronic noise with a lowering of blood pressure (Welch, cited in Hattis and Richardson, 1980). The use of sub-adult baboons in the present study is suggestive in this connection, and may account for the differences in cardiovascular effect between the present study and the similar study of Peterson et al. who used relatively old (5-8 year old) rhesus monkeys.

Significant correlations between plasma norepinephrine and blood pressure level have been previously reported in baboons (Goldstein, Harris, Izzo, Turkkan and Keiser, 1981). In this study as well, plasma norepinephrine and epinephrine were decreased in conjunction with blood pressure decreases, pointing to an overall decrease in adrenergic activity (and a possible increase in vagal tone, as suggested by the correlated lowering of heart rate levels). A recent study (Andren, Hansson, Bjorkman, and Jonsson, 1980) indicates a more inotropic than chronotropic influence of noise in that significant decreases in stroke volume and cardiac output were obtained in the absence of significant change in heart rate in human subjects (26 years old) exposed to 95 dBA noise.

Because anticipatory blood pressure and heart rate increases were apparent prior to feeding times, meal times were manipulated in Baboon MI

to examine the possibility that food-induced cardiovascular changes were masking the noise onset and offset effects. When morning feeding was eliminated (total daily food was kept constant), noise onset resulted in an acute blood pressure decrease, suggesting that the hypotensive effects of noise may be heightened by careful consideration of noise exposure times in relation to feeding times. The possibility also exists that noise assumed the properties of a conditional stimulus (CS) for food, resulting from the daily regularity of the noise onset - food presentation interval. Acute blood pressure increases as conditional responses to food-related stimuli have been reported previously in the monkey (Billman, Hasson, and Randall, 1978). The notion that an extremely intense stimulus such as noise cannot act as a CS is contradicted by the counterconditioning literature where it has been shown, for example, that an intense electric shock results in salivation in dogs when shock regularly predicts food (Frolov, cited by Pavlov, 1927). Thus, the acute blood pressure increases observed during the noise onset - food presentation interval may have been conditioned responses, a suggestion strengthened by the finding that when food was eliminated, the pressure increases during that interval were also eliminated.

In all, these studies point to a more complex effect of noise on the cardiovascular and hormonal systems than has been hitherto suggested. Although the amount of controlled animal experimentation in this area is growing, many aspects of the non-auditory effects of noise remain to be clearly delineated.

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PRINCIPLES FOR DRAFTING AND ENFORCING LEGISLATION TO PROTECT WILDLIFE FROM ENVIRONMENTAL NOISE

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In part, the subject of this paper is an obscure one. In a world where the destruction of wild animals and their habitat is proceeding at an alarming rate, noise is the least of worries. The sound of the chain saw is insignificant compared to the loss of another tree from the tropical rain forest. The poacher's bullet ends the life of the elephant just as effectively whether or not the rifle has a silencer. Yet there is always the hope that, through enlightenment and technology, the destruction will cease and that the great habitats of Africa, Asia and South America will be stabilized. If and when that happens, control of noise from transportation and recreational vehicles would become a concern just as it is in the wildlife areas of Europe and North America.

The purpose of this paper is to pave the way for such control by (1) laying out a logical framework for drafting legislation and (2) exploring the technological innovations required for drafting such legislation.

The data for developing the logical framework comes from the United States experience under its National Environmental Policy Act of 1969. This law, which dictated that environmental consequences of any Federal action had to be considered, has provided a number of examples in which the effects of noise on wildlife have been addressed. The philosophy for interpreting these data is the admonition of a comparative psychologist, E.C. Tolman (1932) who advised students to view the paraphernalia of instrumental learning (mazes, bar presses, escape boxes) from the mind of the animal subjects. Tolman's message applies just as well to drafting noise laws for wildlife. Questions that follow from the Tolman perspective are:

(1) How loud is the noise to the species of interest?

(2) Does the noise, per se, pose a threat?

(3) Can the species adapt without adverse physiological consequences?

The question of how loud (or annoying) is the noise follows from differences in auditory sensitivity. Examples from common species of the North American woodland are the turtle with best sensitivity of 40 dB SPL at 200-400 Hz (Patterson, 1966), red-wing blackbird with 4 to 20 dB at 2 to 4 kHz (Hienz et al, 1977), the owl with -20 to -10 dB SPL at 1 to 6 kHz (van Dijk, 1973), the raccoon with -15 to 0 dB at 1 to 10 kHz (Wollack, 1965), the rabbit with 0-10 dB at 2 to 16 kHz (Heffner and Masterton, 1980), opossum with 20 to 25 dB at 3 to 30 kHz (Ravizza et al, 1969), the

mouse with -10 to 0 dB at 16 kHz (Heffner and Masterton, 1980) and the bat with 0 to 10 dB at 10 to 100 kHz (Dalland, 1965). Although all are sensitive to sound, it is unlikely that any one source would be equally loud to all. For example, an off-road vehicle with maximum energy at 2 kHz should produce the highest sensation level for the owl, raccoon and rabbit, a lesser level for the red-winged blackbird and opossum and an insignificant level for bat or mouse or turtle.

If in drafting laws, one assumes that what is noisy to man is also noisy to animals, there is a risk of (1) ban to noise which is non-harmful and (2) ignoring noise which is harmful. An example of the former comes from an EIS on a wind-powered generating station at San Gorgonio Pass in California (US Dept of Interior, 1982) which suggests that noise may hurt the Coachella Valley fringe-toed lizard. In arriving at this conclusion, the authors use A-weighted noise measurements. Clearly, this is an error of logic. A-weighting simulates human sensitivity. If one compares human sensitivity with one of the better developed lizard auditory systems (Tokay gecko from Thailand), there is an average energy difference of 48 dB in favor of the human over the range of 125 to 8000 Hz (Eatock et al, 1981)!

The other danger in judging noise from our human perception is ignoring noise which disturbs wildlife. A good example is infrasound. There is reason to believe some species are more sensitive to infrasound. One example is

the North American mountain beaver, a rodent whose dorsal cochlear nucleus (DCN) is much larger than in other rodents (Merzenich et al, 1973). Matching the hyperdevelopment of the DCN is an unusual sensitivity down to 10 Hz. Merzenich et al found thresholds for organizing spontaneous neural activity as low as 40 dB SPL. They suggest a possible role of low frequency sensitivity in detecting approaching storms. Similarly, Kreithen and Quine (1979) suggested infrasound sensitivity in the homing pigeon may be a navigational aid. Using behavioral audiometry, they found the homing pigeon to be 50 dB more sensitive than man below 10 Hz. Evidence that some species are more fearful than man in the presence of infrasound comes from the study of earth quake prediction (Kerr, 1980). Low level tremors can generate booms sounding like distant artillery fire. When exposed to these booms, dogs may begin howling. Chinese sources report more intense reactions, i.e., chickens refusing to enter coops, cows breaking halters and police dogs not obeying commands (Kerr, 1980). Similar responses have been reported with artillery noise. In an analysis of noise complaints received by the US Army, Luz et al (1982) found that five percent mentioned nervous reactions in animals.

The second question of interest is whether noise is really the threatening stimulus. Consider, for example, Luz and Smith's (1976) study of the antelope's response to helicopters. In this study, a photographic record was ob-

tained as an OH-58 helicopter flew toward a group of antelope. At a kilometer, the antelope were unreactive (60 dBA) and at 50 meters they fled (77 dBA). The question is whether they fled because the noise was 77 dBA or because the helicopter was 50 meters away. This question could have been resolved by running a comparison test with a noisier craft but, because the antelope were so few, the test would have been harmful. In contrast, studies of the response of whales to boat noise provide stronger evidence that noise is the primary disturbance. Fraker (1981) showed effects on bowhead whale out to one kilometer. When engines were turned off, the behavioral responses ceased. No change in behavior was observed at 3.7 kilometers. If whales are responding to a given level of noise, then criterion levels can be developed. A step in this direction is a recent study funded by the US National Marine Fisheries Service (Miles and Malme, 1983) which reports the noise levels of various vessels using the habitat of the humpback whale in Glacier Bay, Alaska.

Even when noise can be effectively separated from the visual stimulus, the degree of threat will depend on the animal's interpretation. Returning to the whales, it is clear that whales will react positively to some engine noise. Thus, Dahlheim et al (1981) observed gray whales staying up to three hours in close proximity to idling outboard engines. Some whales terminated this activity when the engines were shut off. Similarly, White et al (1979) found

hawks in Idaho's Raft River Valley to be undisturbed by Air Force bombing runs in which the sound stimulus arrived at the nest after the visual stimulus. In contrast, the addition of a hidden beeper 200 meters from the nest led some hawks to abandon their site.

The third question on the ability of the species to adapt to the noise without adverse physiological consequences echoes the literature on the adverse physiological consequences of noise in many species (Peterson, 1980) As with any other noxious stimulus, noise, if it is loud enough, is a stimulus to be avoided (Beluzzi and Grossman, 1969). At the same time, animals are motivated to occupy open territory. Thus, the presence of a source in the environment poses the same kind of approach-avoidance conflict as explored by the behavioral psychology of the 1940's (Spence, 1956). The textbook example is the hungry rat who must cross an electrified grid to get food. By manipulating the amount of food, the size of shock and the degree of hunger, experimenters could manipulate the position of the rat within the apparatus. For noise, those species under strong population pressure will tolerate high levels. One example is a study of wild mice at the Memphis Tennessee Airport (Pritchett et al, 1976) in which the adrenal glands of mice exposed to single events of 110 db SPL were compared to those exposed to single events of 85 dB. Although mark-recapture analysis showed no difference in population density, the noise exposed mice showed decrease

in adrenal cortical responsiveness to ACTH. Even if noise is not so intense that one would expect physiological changes, there is a need for psychological habituation. An important variable in habituation is predictability. Thus in the study of hawks (White et al, 1979), the birds would build nests in the vicinity of noisy drilling rigs but would abandon nests when the same level of noise was added to a previously quiet environment.

If, after listening to the noise through the brain of the species to be protected, regulators still feel a need to protect a species, there is a problem of enforcement. Clearly, the kind of noise most harmful is from sources least likely to be detected (e.g. aircraft, trail bikes, terrain vehicles.) To protect against intrusion, one would need a permanent guard. Fortunately, with today's computer technology, posting a permanent guard is feasible. As an example, consider the US National Park Service's recent decision to close a number of Alaskan parks to snowmobiles, motorboats, all terrain vehicles, ships and aircraft use (Anonymous, 1983). Given that these lands are large and that the staff is small, how could one detect a violation? Although there is no equipment available to do the job, minor modifications to existing equipment would be easy. Consider, for example, the block diagram in Figure 1 showing the design of an industrial noise dosimeter manufactured in the US and retailing for under $1000. In this device, an acoustical signal is passed through an A-weighting network and then converted to a digital signal. A

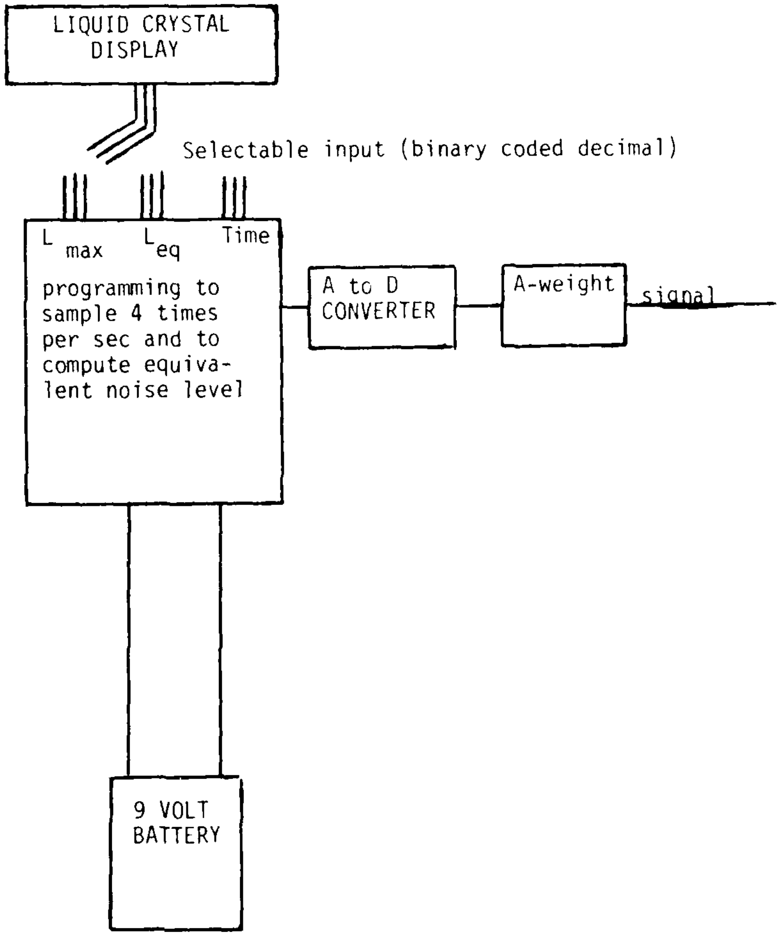

Fig. 1 - Block diagram of commercially-available noise dosimeter

microprocessor samples the signal at the rate of four per second and takes the energy average. The unit has small power requirements, operating for three days on a 9 volt battery. A selectable switch allows the user to read the maximum level from any sample, the equivalent level for the time of operation and the duration of operation. Data are displayed on a liquid crystal display.

As now designed, the device in Figure 1 would not be useful in guarding noise-sensitive areas such as eagle nests. In general, the device is intended to record a cumulative noise exposure at the end of a workday and it is not intended to operate on line. Although the same manufacturer does have a newer dosimeter connectable to telephone lines, putting lines into a wilderness area would be both expensive and visually offensive. Additional problems would be lack of a critical threshold, use of A-weighting, and use of a cumulative noise dose. Some modifications to eliminate these problems are shown in Figure 2. Batteries have been replaced with solar cells and the problem of getting on line information from the site to an enforcement authority (e.g. Park Ranger Station) is solved by a directional FM transmitter. A threshold is provided by replacing the liquid crystal display with a user adjustable AND gate for the binary coded decimal output. To get around the problem of A-weighting, the circuit can now be tuned to a species audiogram (e.g. EAGLE-weighting). Finally, to allow for detection of short term increases in noise level, an adjustable timer is provided. In effect, these last three modifications form an "electronic summary" of the principle points in this paper. As the cost of such technology continues to drop, there is good reason to hope that the goal of protecting wildlife areas from noise can be met.

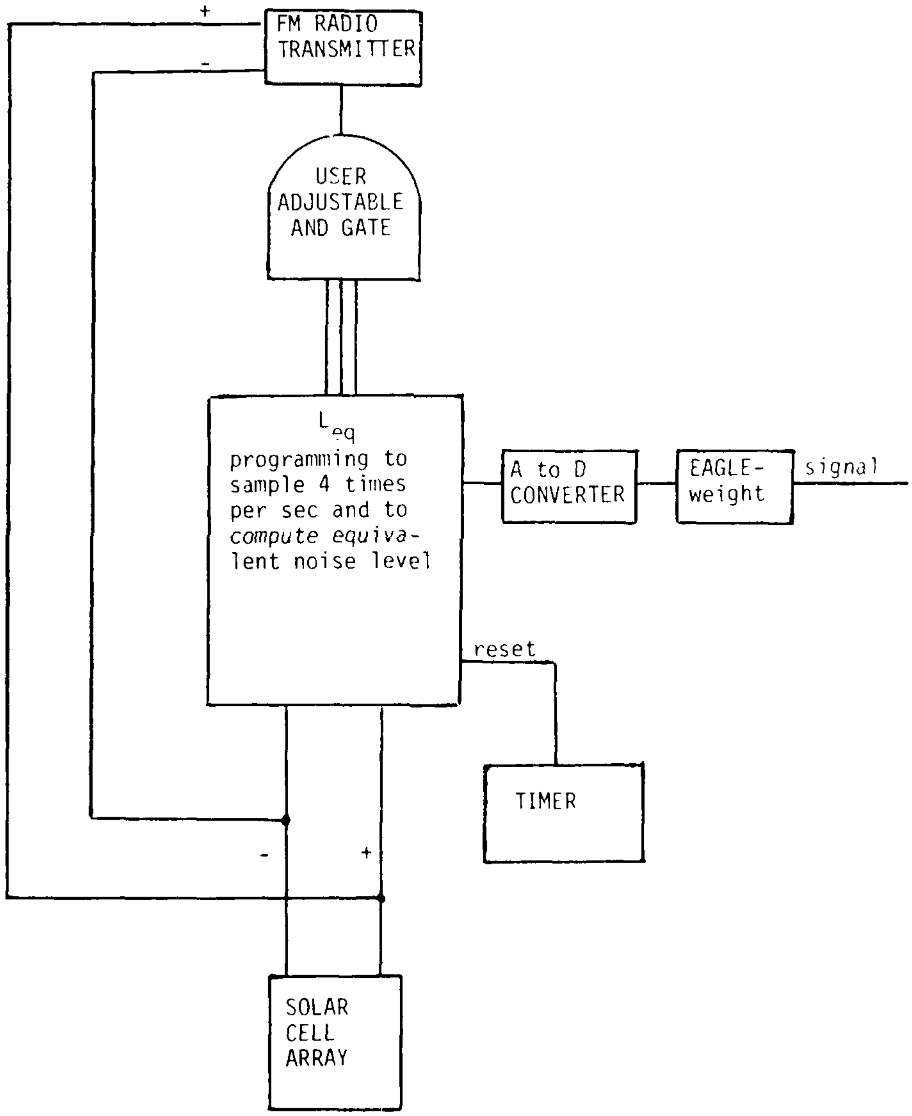

Fig. 2 - Block diagram of proposed modification of commercial dosimeter

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PROPOSAL FOR A SCIENTIFIC PROGRAM

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I. A first step is to convince appropriate authorities of the need for research on noise effects, with research to be done on topics related to public needs and complaints. Some countries have specific problems such as sonic booms, whales, airports, pipelines, etc. and farmers, animal lovers and conservationists must all be considered. For that reason, we find it difficult to make detailed recommendations on an international scale.

II. All experimental studies, field or laboratory, should be conducted by an interdisciplinary team to maximize data validity and to facilitate comprehensive interpretation of the data and include the viewpoint of the ethologist, physiologist, acoustician, and behaviorist.

III. Regarding problems of wildlife and other animals, too little scientific data have been published in

the last 15 years about the combined effects of noise and <u>other</u> stressors. In particular, the presence of humans as a factor has appeared to be ignored or inadequately controlled.

IV. It is vital that we have data from both acute and chronic studies, and with laboratory studies of caged animals, avoiding human manipulation or intrusion is important.

V. Use of deafened (deafened genetically, surgically, or chemically) animals as controls would be a useful technique to account for acoustic sensitivity differences among animals and to study noise combined with other stressors.

VI. Recent data from experimental animals provide us with information about the synergistic effects of noise and other possible factors. However, we still need information about the possible synergistic effects of such things as chemicals, germs or viruses, metabolism, etc.

VII. Because animal acoustic sensitivities vary widely from infra to ultra-sound, noise surveys should include these frequencies.

VIII. Studies should be made of the specific behavior of social animals both as individuals and within social groups during such times as mating, feeding, nur-

turing, etc. This has not been done and only anecdotal evidence is available. It can be critical for some endangered species to have such information, for example for the bowhead whale in North America.

IX. Studies of marine ambient noise levels and marine organisms are needed, with careful discrimination between the effects of noise and those from other factors such as physical intrusion.

X. As a final recommendation, we suggest all the preceding recommendations be carefully considered!

Closing Session
Noise Reduction and Costs

Chairman: H.E. v. Gierke (U.S.A.)

INTRODUCTION

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When most countries enacted environmental legislation one-and-a-half decades ago the question arose: How much protection of the environment is justified and at what costs? Many countries introduced Environmental Impact Statements (EIS) as the means to formally analyze the impact of major projects or changes affecting the human environment. The purposes of these EISs were to quantify the impact, to explore alternate solutions which might have a smaller impact, and to allow at least a semi-quantitative cost-benefit analysis of the overall project. Noise is one of the environmental pollutants to be addressed in an EIS and guidelines to prepare EISs with respect to noise have been prepared (1), (2) and are in use in various forms in many countries. The number of people exposed to levels exceeding specific exposure criteria is usually taken as a measure to assess the severity of the noise impact. The potential average hearing loss from the noise exposure or the number of people reported to be highly annoyed by the noise environment have been used as noise impact criteria, based on quantitative measures reasonably well supported by real-life dose-response relationships. Changes in the noise environment can so be related to changes in the effects of the noise; the costs of noise reduction can be compared to a quantity related to the benefits from the reduced noise effects.

The first step in such an analysis is the characterization of the noise environment: How noisy is an environment? What is the noise "climate" today compared to 10 years ago? Were the control measures effective? What will be the changes in the coming years? These questions are not only of interest for an individual situation, but also for whole countries and the total world. Is the world getting noisier by 1 dB per decade as some have predicted? Were all the expenditures and efforts to control aircraft and traffic noise effective? The tools and data bases to do studies like these are still limited. The estimates and predictions made ten years ago have not been verified, as originally proposed, by well-planned surveys and long-time monitoring of the noise exposures of areas as well as people. This is unfortunate because such

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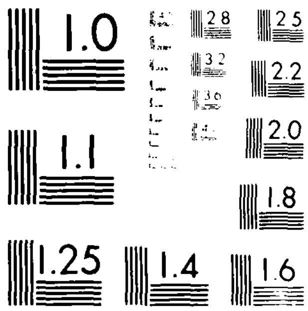

MICROCOPY RESOLUTION TEST CHART

data would document changes in noise impact and in the real-life effectiveness of efforts to reduce the major noise sources as well as the noise exposure of people.

This closing session of our congress was arranged by the program committee to look at the problem of noise reduction and its costs. We have as speakers three individuals with outstanding experience in this area, who will report on the subject from the viewpoint of their respective organization or country. They will discuss progress in noise abatement and cost-benefit considerations applied in various countries and to various noise sources; they will talk about the definition, measurement and prediction of noise exposure of whole populations and about the quantification and verification of benefits and costs. In summary it is hoped that these papers will be helpful in assessing our present and in predicting and shaping our future noise environment.

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HOW DO WE DESCRIBE NOISE EXPOSURE AND HOW MUCH DOES ITS REDUCTION COST?

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INTRODUCTION

This paper proposes that the linear quantity of sound exposure be utilized as the basis for describing exposure to environmental noise, both in the workplace and the outdoor community. Its use should reduce the confusion resulting from the proliferation of the various types of decibels and enable the additive and proportionate properties of the sound exposure to be utilized in the same manner as they are in almost all other fields.

The proposed quantities are utilized in summarizing the 1980 noise exposures, and noise impacts encountered in the U.S.A. in terms of the estimated populations affected and examples of the estimated costs to reduce the sound exposures.

DESCRIPTION OF NOISE EXPOSURE

The majority of noise data for both the workplace and the outdoor community environments have been obtained with sound level meters. These instruments provide a direct reading of a frequency weighted sound level in decibels (dB). The frequency weighting most commonly used for environmental noise with respect to humans is the A-weighting. In the U.S.A. the phrase "sound level" is taken to mean the A-weighted sound level unless another frequency weighting is stated.(1) In Europe the same quantity is generally called the "A-weighted sound pressure level."(2)

Other frequency weightings B, C and Flat may be found in many sound level meters and are of use for various purposes. Additionally, the frequency weighting, D (2) and E (3), have been proposed to replace the A-weighting for the measurement and assessment of environmental noise with respect to humans. These weightings model the human hearing process in a manner that is more relevant to the assessment of noise effects; both in the frequency region between 1 and 6 kilohertz (Khz) where head diffraction and ear canal resonances have important effects on hearing, and at the low frequencies when the A-weighting understates the level of typical noises. However, since neither of these weightings has achieved common use for environmental noise, the descriptions used in this paper are all based on the A-weighting.

The concept of "noise exposure dose" has existed for a long time (4) in the assessment of the potential for hearing damage risk and for over 30 years in the assessment of community noise. (5) However, until recently, no instruments existed that could directly measure "noise exposure dose." Consequently, workplace noise exposure was not described explicitly (e.g., the noise exposure is ___); but rather implicitly in terms of the sound level and the time of exposure (e.g., the exposure was ___ decibels [or dB (A)] for ___ hours). For those situations in which the sound levels of the workplace noise environment varied with time, no single reading of sound level was appropriate. Consequently, a quantity was conceived to represent the long time mean square weighted sound pressure. This quantity was called (in Europe) the equivalent continuous A-weighted sound pressure level (L_{AeqT}) or (in the U.S.) the equivalent sound level (6,7) (also known as time-average sound level). Thus, LEQ is simply the level of a continuous steady sound which is equivalent to a sound of similar duration whose level varies with time in the sense that both have the same value of the time integral of their mean square pressure time histories. Recently in the draft International Standard on hearing conservation (9) this integral was explicitly defined as the "time-integrated squared A-weighted sound pressure" with the symbol E_{AT}. In the U.S. this quantity was already known as sound exposure. It has also been used as the basis for calculating still another "level" known as Sound Exposure Level. The sound exposure for an eight-hour equivalent sound level of 90 dB is 11,520 pascal squared seconds (or 11.5 kilo pascal squared seconds).

The concept of equivalent sound level also has been extended to the community noise environment to describe the day, evening and night sound environments and to the total 24 hour day. The descriptor for the outdoor community noise chosen in the U.S.A. is called the Day-Night Sound Level (L_{dn}) (8) and is determined by calculating the 24 hour equivalent sound level after weighting nighttime noises (sounds occurring between 10 P.M. and 7 A.M.) by a 10 dB penalty. The nighttime penalty is added to account for the presumed greater sensitivity of people to intrusive nighttime noises considering both sleep requirements and the typical lowering of outdoor ambient noise during the nighttime hours. When averaged over an entire year the yearly average day-night sound level may be used to provide a stable single number descriptor for the noise environment at a community location.

The community noise environment may also be described in terms of the day-night sound exposure which is the day-night weighted 24 hour integral of the squared A-weighted sound pressure. The day-night sound exposure is 1.0 pascal squared second for an L_{dn} of 44.614 dB. Thus, 1-1000 on its scale encompasses the range on the day-night sound level scale of most interest, 45 to 75 dB.

The existance of new instruments that have the capability to measure sound exposure together with the increased interest in using some derivative of sound exposure for describing environmental noise exposure present a unique opportunity for choice. Traditionally, we have used a variant of the decibel in all environmental noise descriptors. But, in the new "digital" world there is no requirement that all noise descriptors be stated in some type of decibels. On the contrary, there are many reasons why a non-decibel like quantity could be preferred.

(1) The public and lay professionals understand that the "decibel is a measure of noise." However, when the acoustician uses more than one kind of decibel confusion and mistrust often occur, making multi-disciplinary discussions of the assessment and alternative solutions to noise problems more difficult than necessary. Sound exposure is a linear quantity, not a logarithmic quantity like decibels.

(2) Both a community's day-night sound exposure at a location and an individual's personal 24-hour daily noise exposure usually consists of several separate sound exposures. Often these separate sound exposures involve different sources and/or activities, that are most easily measured or calculated separately, then summed to determine the total sound exposure. Sound exposures are directly additive, without transformation.

(3) Often it is desirable to state that the measured noise as a percentage of a criterion value or that the noise has been reduced by a stated percentage. Such statements are standard in almost all fields except noise where the logarithmic nature of the decibel requires the use of other rules. The linear properties of sound exposure enable the direct use of percentages and fractions as appropriate.

In summary it is believed that the use of a linear quantity to express the concept of noise exposure dose would facilitate communication with the public and other non-acoustical interested persons; by not confusing the discussions with more than one type of decibels, enabling the simple addition of various sound exposures and the proportionate increase or decrease of sound exposure with increase or decrease in the duration of exposure or the number of similar noise events.

The proposed descriptors for noise exposure are summarized in Table 1.

Table 1 Descriptors For Environmental Noise In The Workplace And The Community

Noise Characteristic	Name (Long Title)	Symbol	Abbreviation	Units
Magnitude of time varying sound	Sound Level in decibels re 20μ pascals (Slow A-weighted sound pressure level)	L_{AS}	SAL	decibel (dB)
Noise Exposure	Sound Exposure (Time integrated squared A-weighted sound pressure)	E_{AT}	TAE	pascal-squared-seconds ($Pa^2 \cdot S$ or pasques)
Personal Daily Noise Exposure	Daily Sound Exposure (Twenty-four hour integrated squared A-weighted sound pressure)	E_{AD}	DAE	pascal-squared-seconds (or kilo $Pa^2 \cdot S$, kilo pasques)
Outdoor Community Noise Exposure	Day-night Sound Exposure (Twenty-four hour day-night weighted time integrated squared A-weighted Sound Pressure)	E_{Adn}	DNE	pascal-squared-seconds ($Pa^2 \cdot S$ or pasques)

INDIVIDUAL NOISE EXPOSURE WITH RESPECT TO RISK OF HEARING DAMAGE

The estimated number of people in the U.S.A. whose yearly average occupational daily sound exposure potentially exceeds 3.6 kilo $Pa^2 \cdot S$ (L_{Aeq8} > 85 dB) is 9.2 million.(10) As indicated in Table 2, over one-half of these people are production workers in industry.

Also shown on Table 2 is the number of people whose daily sound exposure from non-occupational activity exceeds 0.36 Kilo $Pa^2 \cdot S$. This is the value of the sound exposure that was selected by the U.S. Environmental Protection Agency (8) as "requisite to protect the public health and welfare with an adequate margin of safety" with respect to hearing risk. This value was selected to be approximately 1/3 of the minimum value at which a change in hearing threshold was expected to be measured reliably. The estimates for non-occupational use are necessarily averages and approximate. The actual situation is expected to involve a distribution of use durations and operator sound levels about the averages, such that some of the people shown as exceeding 0.36 Kilo $Pa^2 \cdot S$

probably also exceed 3.6 Kilo Pa^{2}S. This condition is expected particularly for exposure to the noise of snowmobiles, motorcycles and outdoor power equipment. These devices had the highest estimated average daily sound exposures and are known to have a considerable variation in operator sound level.

Table 2 Estimate of Number of People (In Millions) Potentially Exposed To Noise Exceeding 0.36 and 3.6 Kilo pasques (L_{eq8} Levels of 75 and 85 dB) from Occupational and Non-Occupational Activities (10)

Occupational Sound Exposures Exceeding 3.6 Kilo pasques	# of People	Non-Occupational Sound Exposures Exceeding 0.36 Kilo pasques	# of People
Agriculture	0.3	Gen. Avia. Aircraft	0.4
Mining	0.4	Motorcycles (road)	5.2
Construction	0.5	Buses	10.4
Manufacturing	5.1	Rapid Transit	2.0
Transportation	1.9	Snowmobiles	1.7
Military	1.0	Motorcycles (off-road)	2.6
		Motorboats	2.3
Total	9.2	Power Shop Tools (Home)	30.7*
		Outdoor Power Equipment (Home)	11.0*
		Total	77.7*

*These totals probably include overlap from double counting.

In the United States the authority for occupational noise standards is assigned to one of several Federal agencies, as appropriate to the area. The largest group of workers who are potentially exposed to noise levels which might cause hearing damage are the production workers in industry. Noise standards for these workers are established by the Occupational Safety and Health Administration (OSHA) of the U.S. Department of Labor. Since the early 1970's OSHA has had a standard that requires the application of engineering controls, when feasible, when the workday time weighted average (TWA) noise level exceeds 90 dB. The TWA is calculated using a 5 dB rule for halving allowable duration, such that 8 hours at 90 dB, 4 hours at 95 dB or 2 hours of 100 dB each have a 8 hour TWA noise level of 90 dB. The current standard also requires the implementation of a hearing conservation program which involves both audiometric tests and use of personal protective devices when the TWA noise level exceeds 85 dB. (Note that the 5 dB/halving rule used in calculating the time-weighted average noise level permits relatively greater durations at levels above the standard level and lesser durations at levels below the standard level than does the 3 dB/halving rule used in calculating equivalent sound level.)

A 1975 study (11) sponsored by OSHA obtained noise data in 68 plants that were selected to be distributed among 19 industries. The sample plants employed approximately one-half of one percent of the production workers in those industries. The distribution of production workers with TWA noise levels for these industries is given in Table 3. Although these data are based on a very small deterministically derived sample of plants, an unpublished, more broadly based and larger sample supports

the results shown for total industry. However, significant differences are found in some of the individual industry segments, as would be expected.

Table 3 Percentage of Production Workers in 19 Two-Digit Industries Potentially Exposed to Noise (12, 13)

Industry Name	Time Weighted Average Noise Level Exceeds				
	100 dB	95 dB	90 dB	85 dB	80 dB
Food	1	6	16	28	47
Tobacco	1	3	7	10	28
Textiles	14	33	52	75	87
Apparel	0	0	0	1	20
Lumber & Wood	8	35	72	94	97
Furniture & Fixtures	0	2	12	30	53
Paper	.4	6	21	40	59
Printing & Publishing	0	4	19	45	66
Chemicals	.1	6	20	37	55
Petroleum & Coal	14	31	52	74	82
Rubber & Plastics	.3	2	9	20	40
Leather	0	0	0	1	20
Stone, Glass & Clay	1	2	5	16	42
Primary Metals	8	20	38	63	81
Fabricated Metals	4	11	19	34	56
Machinery (not Electric)	3	6	13	26	48
Electric Machinery	.1	.5	.3	7	27
Transport Equipment	3	7	13	23	42
Utilities	0	0	30	74	89
TOTAL INDUSTRY	2.9	8.3	19.3	34.4	53.1

The 1975 study (11) also estimated the costs of "a best effort" for engineering controls. The estimates were made for two assumed TWA noise level standards, 85 dB and 90 dB (the existing standard). The study estimated a total program cost of $10.5 Billion to achieve the 90 dB standard for 97% of those originally potentially overexposed (i.e., engineering controls for 3% were considered technically infeasible). The similar estimate for the 85 dB standard was $18.5 Billion for 93% of those originally potentially overexposed.

Table 4 summarizes the principle cost results of this study. It is interesting to note that there is no statistical difference at the 5% level between the weighted and unweighted averages and between the averages for each standard noise level. Therefore, the increase in total cost to achieve a standard of 85 dB was found to be proportional to the increase in the number of potentially overexposed workers. Since the number of machines to be quieted is presumed to increase along with the number of workers, the implication is that the measures designed to quiet machines to 90 dB were in many cases sufficient to quiet these machines to 85 dB at little additional cost. Then the additional cost to attain 85 dB would be primarily that required to quiet machines that did not require noise control to meet the 90 dB standard. This situation is believed to result from the use of noise enclosures as the primary noise control device for the study.

Table 4 1975 Estimate (13) of the Number of Potentially Overexposed Production Workers (i.e., Production Workers Potentially Exposed to Time Weighted (5 dB Rule) Average (TWA) Noise Levels in Excess of 90 or 85 dB) and the Costs to Reduce These Noise Levels Through Maximum Application of Engineering Controls

	TWA NOISE LEVEL GREATER THAN					
	90 dB			85 dB		
Industry	Cost ($ Mil)	Number of Potent. Overexp. Prod. Workers (000)	Cost/ Potent. Overexp. Prod. Worker ($)	Cost ($ Mil)	Number of Potent. Overexp. Prod. Workers (000)	Cost/ Potent. Overexp. Prod. Worker ($)
Food	$ 575	180.2	$3,190	$ 1,675	315.4	$ 5,310
Tobacco	45	4.2	16,940*	105	6.2	14,110*
Textiles	1,155	390.5	2,960	2,470	563.3	4,380
Apparel	0	0	0*	15	10.2	1,460*
Lumber&Wood	700	325.1	2,150	1,140	424.4	2,690
Furniture	360	42.4	8,490	445	106.0	4,200
Paper	200	101.0	1,980	310	191.4	1,620
Print.&Pub.	470	122.1	3,850	1,150	289.1	3,980
Chemicals	305	113.4	2,690	625	209.9	2,980
Oil&Coal	175	63.1	2,770	260	92.2	2,820
Rubber&Plast.	115	39.2	2,930	245	88.1	2,780
Leathers	0	0	0*	10	2.1	4,760*
Stone&Glass	170	23.2	7,330	385	77.4	4,970
Prim. Metals	1,395	358.6	3,890	2,925	594.6	4,920
Fab. Metals	1,305	169.6	6,880	1,560	339.3	4,600
Mach.(not Elec.)	2,185	179.8	12,150	2,820	359.7	7,840
Elec.Machinery	145	28.6	5,070	370	80.0	4,630
Trans. Equip.	670	147.4	4,550	1,050	260.8	4,030
Utilities	575	185.8	3,095	980	458.2	2,139
Totals	$10,545	2,494.2		$18,540	4,468.4	
Unweighted Avg.**			$4,620			$ 3,990
Weighted Avg.***			$4,230			$ 4,150

*Not included in average because industry has less than 10,000 production workers exposed at 90 dB.

**Based on average of 16 unweighted values of cost/potentially overexposed production workers.

***Based on total cost ÷ total number of potentially overexposed production workers.

There has been considerable debate about these costs in the U.S. There is some evidence to indicate that present costs would be lower in some industries because of the technology learning curve since 1975 and because of the large increase in availability of standard noise control components. In other industries the present costs would be lower because the noise controls originally contemplated have proved to be infeasible. Consequently their costs would be removed from the totals, but the associated workers would be added to those residual workers for whom engineering controls are infeasible. Finally, there are many examples in industry when the present costs are greater than estimated.

COMMUNITY NOISE EXPOSURE WITH RESPECT TO ANNOYANCE

There are five major general sources of outdoor noise in urban communities, of which the noise from traffic and aircraft are usually found to be among the greatest numbers of people. Table 5 summarizes the estimated distribution of residential population and noise with respect to the five general sources. These estimates resulted from various studies (10) made for the U.S. Environmental Protection Agency, and were updated to 1980.

Table 5 Estimated Cumulative 1980 Population (Millions of People) Living in Areas Where The Outdoor Day-Night Sound Level (Or Day-Night Sound Exposure) Exceeds The Indicated Value For Five Major Types Of Sound

L_{dn} Exceeded (dB)	E_{Adn} Exceeded (Pa^2S)	Type of Source: Traffic	Aircraft	Rail	Industrial	Construction
80	3460	0.1	0.1			
75	1090	1.1	0.3			
70	346	5.7	1.3	.2		
65	109	19.3	4.7	1.1	0.3	
60	34.6	46.6	11.5	2.0	1.9	1.0
55	10.9	96.8	24.3	3.6	6.9	6.9

Although it is obvious from the Table that noise from Traffic and Aircraft affect many more people than does the noise from any of the other three sources, it is not intuitively obvious whether Rail or Industrial noise should be next in order in terms of population impact. The answer clearly depends on the relative importance of the intensity of the noise and its extensity as measured by population impacted.

The notion of weighting functions for the purpose of developing a single valued measure of the impact of noise on the affected population was articulated in the early 1970's. Such a single number representation of total noise impact can be used in making decisions amongst alternative noise regulatory designs and as an objective function to be minimized in optimizing noise control measures.

One early suggestion (14) for annoyance impact was to calculate the percentage of people that were highly annoyed at each level of noise, multiply it times the associated population and sum to obtain a single value. In the first application of this constant the percentage annoyed was calculated from a linear regression line and the results normalized

to produce 0 impact at L_{dn} = 55 dB and 1.0 impact at L_{dn} = 75 dB. The first formula utilized for fractional impact (FI) assumed constant

$$FI = 0.05\ (L_{dn} - 55) \quad \text{for } L_{dn} > 55$$
$$= 0 \quad \text{for } L_{dn} \leq 55 \qquad (1)$$

This concept was developed into the fractional impact methodology and used for estimating impacts and benefits of alternative regulations by the Environmental Protection Agency (EPA). (15) In 1977 the National Research Council Committee on Hearing Bioacoustics and Biodynamics (CHABA) working group 69 developed a refined definition.(16) The weighting function was based on the percentage highly annoyed found by Schultz (17) in his analysis of a large number of annoyance surveys. His relationship of percent highly annoyed versus L_{dn} was normalized to produce a weighting factor ($W(L_{dn})$) which was normalized to unity at L_{dn} = 75 dB, just as is Equation (1). This method has been used in the evaluation of regulatory benefits by the EPA.

The level weighted population (LWP) concept of CHABA is an attempt to account for both the extensity of the noise impact through accounting for the population impacted, and the intensity through weighting the affected population in proportion to the expected percentage of highly annoyed. Thus, LWP is actually directly proportional to the total number of people estimated to be highly annoyed. It implicitly states that the noise impact in a situation where 2,000 people in a population of 20,000 people (10%) similarly exposed, are estimated to be highly annoyed is the same as that in a situation where 2,000 people in a population of 4,000 people (59%) are estimated to be highly annoyed. Yet the estimated values of L_{dn} associated with these two situations are 61 dB for the situation with 10% estimated highly annoyed and 79 dB for the situation with 50% estimated highly annoyed.

Are these actually equal impacts? If each were to be the calculated result of analyzing a proposed project alternative - should they be judged as equivalent - i.e., equally acceptable or equally non-acceptable? And, if there were only these two project alternatives, which would be chosen as the better alternative?

Although these two hypothetical situations may seem extreme, the fundamental dilemmas they pose often exist in real situations. They exist because for many real noise situations only a small number of people reside close to a source where the sound levels are high, and a much greater number of people reside farther from the source where the sound levels are lower.

Airport optimization studies using LWP as an objective parameter often produce optimum solutions which feature primarily small noise reductions that affect the large number of people residing in areas where the sound levels are lower. Conversely, solutions for the people residing in areas where the sound levels are higher are rarely optimum in terms of LWP and cost. This discrepancy was recently noted in a study of alternative preferential runway utilization rules at Logan.(6) In that study the lay decision-makers tended to give considerably more weight towards reducing the noise in areas of highest L_{dn}, even at the cost of increasing the total impact as measured by LWP.

The introduction of day-night sound exposure offers a new possibility to develop a single number descriptor by simply summing intergrating the individual day-night sound exposures over the entire population affected.

The result may be called population weighted day-night noise exposure. Although it has a direct physical significance its use as an impact function requires practical tests to determine if it points towards the same conclusions as those reached by informed lay juries.

Table 6 compares the population weighted day-night exposure and the CHABA weightings for the aircraft data from Table 5. It is clear from the two columns showing the percentage of the total that the sound exposure weighting gives relatively more weight to populations affected by the higher sound levels as compared to the CHABA weighting. For example, with sound exposure, 77% of the total occurs at L_{dn}'s g[illegible] er than 65 dB compared to 41% for the CHABA method. This result s[illegible] s to be consistent with anecdotal experience.

Table 6 Estimated population impact of aircraft noise based o[illegible] pulation weighted by day-night sound exposure and by the CHABA wei[illegible] (proportional to percentage highly annoyed)

		Day-Night Sound Exposure			CHABA Weighting		
ΔL_{dn} (dB)	Pop (P) (mil)	$\bar{E}_{Adn}$ (Pa^2S)	$\overline{PE}_{Adn}$ (mil)	% of Total Above $L_{dn} = 55$ dB	$\bar{C}_n$	$\overline{PC}_n$ (mil)	% of Total Above $L_{dn} = 55$ dB
80-85	.1	6150	615	20.9	1.697	.17	2.2
75-80	.2	1940	388	13.2	1.212	.242	3.2
70-75	1.0	615	615	20.9	.832	.832	11.0
65-70	3.4	194	660	22.4	.538	1.829	24.1
60-65	6.8	61.5	418	14.2	.324	2.203	29.0
55-60	12.8	19.4	248	8.4	.181	2.317	30.5
	Total		2944	100		7.593	100

Table 7 summarizes the population weighted sound exposure for all of the 5 sources of Table 5. Traffic causes 72% of the total, aircraft 22% and the remaining three, 69.

The obvious priority for traffic and aircraft noise control stand out clearly confirming the priorities of the actions already underway in most OECD countries. The data also show that localized site specific noise control action such as installation of highway noise barriers, land use control/conversion near airports and aircraft flight procedures tailored to noise abatement are of importance for areas which have the highest sound levels. Such controls together with source controls which tend to reduce noise at all sound levels, can be apportioned for greatest cost effectiveness.

In the U.S. the Federal Aviation Administration (FAA) is responsible for regulating the source noise characteristics of civil aircraft. The FAA has led in the development of noise requirements for new aircraft and many of its regulations have provided the basis for similar

international recommendations. The cumulative effect of its actions will lead to a significant lowering in aircraft noise impact by the year 2000. It is not possible to make realistic estimates of the costs of these regulations because the achievement of noise control is largely due to the development of more efficient and quieter engines and aircraft with improved low speed performance. Thus the new quiet aircraft are a much more economically viable aircraft than its predecessor and the marginal direct cost of noise control is usually trivial.

Table 7 Estimated population weighted day-night sound exposure (millions of People Pa^2S) for five major types of sources

ΔL_{dn} (dB)	Avg. Sound Exposure E_{Adn} (Pa^2S)	Type of Source: Traffic	Aircraft	Rail (incl. Rapid Transit)	Industrial	Construction	Total All Sources	% of Total
80-85	6150	615	615				1230	9.3
75-80	1940	1940	388				2328	17.5
70-75	615	2829	615	123			3567	26.9
65-70	194	1482	660	175	58		2375	17.9
60-65	61.5	1680	418	55	98	62	2313	17.4
55-60	19.4	974	248	31	97	114	1464	11.0
	Total	9520	2944	384	253	176	13277	100
	% of Total	71.7	22.2	2.9	1.9	1.3	100	

However, in one instance the FAA mandated retirement or retrofit of the early narrow body jet aircraft that did not meet the initial FAR past 36 noise standards. In 1976 the net present value of the cost of that action was estimated (18) to be as high as $440 million, if compliance was based solely on retrofit. Other scenarios involving partial replacement with new efficient aircraft had to lower costs and, if all of the 4-engined aircraft were replaced, to negative costs.

The major source regulation for traffic noise was developed by the U.S. EPA. It involved the progressive reduction of truck noise limits to 83, 80 and 75 dB when measured at 15 meters. The net present value of the cost of varients of that proposed action in 1976 ranged from approximately $940 to 2,650 million.[19] Actually only the 83 dB limit is currently in force with the 80 dB limit to come in force at a later date. The results of this regulation are expected to produce a significant reduction in traffic noise.

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NOISE ABATEMENT TODAY AND TOMORROW.

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1. Noise today

The rapid urbanisation and industrialisation of the Western world have involved an increasingly wide use of vehicles, equipment and machinery as well as the concentration of activities. These phenomena have constituted the main causes of the noise problem which modern societies are now facing. The number of motor vehicles has tripled, the air traffic has increased 10 times and the urbanisation has increased by 50% over the past 20 years in the OECD area.

As a result of this, around 15% of the OECD population (North America, Western Europe, Japan, Australia and New Zealand) - or 100 million people - are

* The opinions expressed in this paper are those of the authors and do not necessarily reflect the views of the OECD.

presently exposed to noise levels in excess of 65 dBA (average Leq 24 hours in front of the most exposed facades of dwellings), i.e. to noise levels considered in many countries as being above the limit of acceptability. What is more, over 50% of the OECD population are exposed to noise levels in excess of 55 dBA, i.e. to levels above the limit of comfort.

Many opinion polls as well as registrations of complaints about the environment in the United States, France, Germany and Japan(1) indicate that noise is ranked as the most annoying single environmental problem.

But the increase of noise is not spread evenly within industrialised nations. Noise levels have increased only slightly in already noisy areas like urban centres, but have increased substantially in suburbs and touristic areas which were before considered as quiet. In addition, the period of quietness during the night is becoming shorter and week-ends are becoming noisier.

There are also important differences between countries and between cities.

In densely populated countries, the proportion of people exposed to noise levels in excess of 65 dBA can reach 30%, whereas in still rural countries, this proportion can be as low as 5%. And in big cities like

London or Paris, the average noise level is 10 decibels higher than in small cities (i.e. a doubling of loudness). This means that in Paris or London, about 50% of the population are exposed to noise levels exceeding 65 dBA.

What are the main sources of all this noise ? One source which must not be underestimated is what is simply called "neighbourhood noise", between and around dwellings, especially in countries where the rapid urbanisation of the fifties and the sixties resulted in the construction of badly insulated high rise buildings. Other sources include industrial noise and construction noise. But the main source of noise annoyance is transport, i.e. traffic noise, aircraft noise, railway noise.

Aircraft noise is an important nuisance around many big cities, especially in the United States where it is estimated that 2% of the population are exposed to aircraft noise levels exceeding 65 dBA. In Europe, however, only 0.2% of the population are exposed to such aircraft noise levels. Railway noise is a nuisance in some rural areas, especially in those places exposed to the noise produced by high-speed trains.

The main source of noise annoyance is motor vehicle. In Europe and Japan, 30 times more people are annoyed by motor vehicle noise that by aircraft noise.

2. Noise tomorrow

The OECD Conference on Noise held in 1980(1) concluded that aircraft noise will probably decrease whereas traffic noise is likely to continue to increase between now and the year 2000.

In the United States, in France and in Australia, it has been estimated that the total area affected by unacceptable aircraft noise levels will be reduced by at least 50% when all first generation jets will have been replaced by the quiet modern aircraft (Boeing 747, Lockheed Tristar, DC 10, Airbus, etc.).

However, traffic noise may continue to impinge on urban areas and will also spread to beaches, mountains, forests and other yet quiet areas. In particular, if noise emission levels are not strengthened, the number of people exposed to unacceptable noise levels (above 65 dBA) will increase by 30% between now and the end of the century. By that time most urban areas will have become permanent "pockets" of noise, as there are permanent clouds of pollution over certain areas. The reasons are the 30% growth in the total number of vehicles between now and the year 2000, the ever increasing mobility of people and goods (more leisure time, development of secondary homes and of tourism, suburbanisation process still going on, growth of intercity traffic because of the development

of medium-sized towns), a greater number of diesel vehicles, at least in Europe (for energy considerations), and the development of new types of leisure vehicles and equipment.

Not only will the number of people exposed to unacceptable noise levels become larger but those exposed to these noise levels will be more sensitive to noise than they are now. This greater sensitivity can be explained by ever increasing expectations of people for a good quality of life; but the main reason is that in the year 2000 populations will be older on average than they are today. As a matter of fact, this is at hand: in 1990 already, people over 65 years will be 100 million for the OECD area, i.e. around 12% of the OECD population in 1990; and even 20% in some countries. Older people are more sensitive to noise than young people, they are also subject to hearing problems which increase this sensitivity; furthermore, they have more leisure time that young people. In fact, most of the people in this age group will be retired and spend their time in the country or in touristic areas, expecting peace and quiet which they will find only with great difficulty.

However, noise increase is not inevitable. If stricter noise emission limits for motor vehicles are enforced (minus 5 decibels on cars and minus 10 decibels on heavy vehicles and motorcycles) by 1985-1990, the

number of people exposed to noise levels above 65 dBA could be reduced to 50% of the current figure in the year 2000. This forecast was made by OECD on the basis of studies undertaken in the United States, France, the United Kingdom, Switzerland and Denmark. It should be noted, however, that such a drastic reduction of noise exposure would be only obtained for noise levels above 65 dBA.

It is true that most "black spots" would be eliminated with more stringent noise emission limits since a 50% reduction of the number of people exposed to noise levels exceeding 65 dBA would be obtained. However, more *stringent noise emission* limits would only slightly reduce or even stabilise the number of people exposed to noise levels in excess of an Leq of 55 dBA (results of studies undertaken in France and Denmark).

This means that a strategy aiming only at strengthening noise emission limits would greatly improve the situation of the people exposed to excessive noise levels but would be insufficient to improve the situation of those exposed to uncomfortable noise levels. "Black spots" would be eliminated but would be replaced by big "grey areas" of noise.

In order to reduce significantly the number of people exposed to noise levels in excess of 55 dBA as

well, a more comprehensive strategy would be needed, combining more stringent emission limits with improved methods of traffic management and modifications of the infrastructures and buildings themselves (sound insulation, noise screens, etc.). In France, for example, such a comprehensive strategy would reduce the number of people exposed to unacceptable noise levels by 80% and those exposed to uncomfortable noise levels by 60%. But the present economic situation is not favourable to such a comprehensive strategy, the costs of which may be considered as too high (although benefits would also be very high). In this climate, even new international regulations strengthening noise emission limits will be difficult to achieve. The implications of this situations is that the realistic prospects for the future remain "grey".

3. Noise abatement policies for tomorrow

Only if additional means of noise abatement on top of the continuous strengthening of emission limits are implemented will a level of acoustic comfort be achieved by the year 2000. Since anyway more stringent noise emission limits will not be sufficient to escape from a general "grey" acoustical area, some imagination is needed: regulations will have to be complemented - in certain cases even replaced - by all kinds of INCENTIVES,

direct and indirect, economic and informative. Noise charges, which exist already on some airports (in Switzerland, in Japan, in the United Kingdom, in Germany) will have to be used more extensively and not only for aircraft. Noise abatement campaigns (including international ones), labelling of quiet products, quiet pilot cities, education in acoustics at school and at university, are examples of noise abatement incentives. Many others may and must be invented if we really want to obtain a quieter environment.

Those incentives - which are needed not only because they constitute a useful complement to regulations but also because they are among the most realistic policy instruments likely to be adopted in a period of economic austerity - present the advantage of being very flexible (compared to regulations) and therefore easy to adapt to future changes.

4. A diversified future

Among future changes, traffic increase, the ageing of the population, and more leisure activities, have already been mentioned.

Other phenomena may also affect the future acoustic climate, some in a quieter direction, others in a noisier direction.

A corollary to the ageing of the population is the reduction in the number of children. This will almost automatically mean a reduction of some noisy behaviours, compensating perhaps the increased noise sensitivity of old people. There are also other factors which will change and affect the noise environment.

The worktime may decrease because more activities will be shared and because there may be more workers working only part-time. The urbanisation process may be more complex in the future: whereas the demand for private homes may still develop in some countries, the desire to come back to live in the centre of cities close to services, leisure and cultural facilities will be felt by young, aged and more generally by small households; at the same time, the population of big metropoles will stagnate or decrease, whereas the population of medium and small towns is expected to increase. Other changes worthwhile to be mentioned are: changes in energy use (more diesels but also more electric vehicles and better thermal insulation), increased use of public transport and of telecommunications, the dislocation of old industrial plants (textile, steel, etc.) which are being moved to developing countries, the rise of new technologies and finally the process of decentralisation and therefore an increased local autonomy.

The acoustic "implications" of these different factors are difficult to assess and predict. However,

since they will probably play a key role in the determination of the noise climate in the year 2000, it is important to include them in any future comprehensive forecast, and in policy formulation.

5. Conclusion

If we want to avoid that the title of this paper means in fact "noise today and abatement ... tomorrow", three actions must be undertaken: (i) comprehensive forecasts of the future noise environment - including changes in life styles which are taking place -; (ii) the strengthening of noise emission limits must be pursued but it should be recognised that this strategy will not be sufficient; (iii) all kinds of incentives should be adopted in order to adjust the noise abatement policy to the present economic situation as well as to the need for a noise climate that would not only be just acceptable, but really comfortable.

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NOISE CONTROL, ITS COSTS AND BENEFITS

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1. In many countries, noise control has become a political issue in recent years. This is particularly the case in countries with a high density of population and a large volume of traffic. One example of this group of nations is the Federal Republic of Germany, where there are 248 inhabitants per square kilometer on average. In North-Rhine Westphalia, the most densely populated of the federal states - the figure is even 5oo inhabitants per square kilometer. There are 67 cities with over 1oo,ooo people in a country which has a total superficial area of less than 25o,ooo sq. kms. 3o million vehicles of various kinds have been licensed for use on the roads of the Federal Republic. Over 45o civil and military airfields serve the purposes of air traffic.

   In 198o, the volume of goods transported by road and rail, water and air came to over 2oo billion tonne-kilometers.

   These data indicate the scale which the problem of noise has reached in the Federal Republic of Germany. For years now, great political importance has been attached to noise control in this country and, accordingly, a great deal has been done to protect the population against noise. In the light of this situation, it is quite instructive to consider the subject of "noise control, its costs and benefits" with reference to concrete activities in Germany.

2. The Federal Republic's noise control policy focuses on the following spheres: industrial noise including the noise caused in the construction sector; aircraft noise; road traffic noise; and interdisciplinary noise research. I would now like to describe some of the activities in these sectors and to express a view on the financial costs as well as the achieved (or anticipated) benefits, as far as they may be expressed in dB(A).

   The first legislative step towards a modern noise abatement policy in Germany was taken in 1965 when the Construction Noise Act (2) appeared.

The operators of construction machines were required to prevent such building noise as was technically feasible according to the latest state of the art and to limit the spread of unavoidable noise from the building site to a minimum inasmuch as this is necessary to avoid dangers, major disadvantages or substantial inconvenience. The assets to be protected were now no longer just human health, but also freedom from "substantial inconvenience" i.e. human well-being in general. The Construction Noise Act, later incorporated into the comprehensive Federal Immissions Control Act of 1974 (3), was implemented by the Federal Government by means of a whole series of individual regulations. For example, varied immission values were laid down for construction noise and - in the case of the most important kinds of construction machinery - emission values based on representative technical and economic market studies. From the very beginning it was stipulated that these regulations would become stricter in the course of a specified number of years. This procedure was very efficient inasmuch as the noise levels of the given construction machinery decreased considerably in the course of a few years, by over 1o dB(A) in some cases. Governmental expenditure was largely confined to the relatively moderate costs of technical market research and to the occasional checking of construction sites. Industrial costs varied from one manufacturer to another But on the whole they were not excessive: this was due, in no small measure, to the generous computation of transitional periods. At any rate, they did not prevent the German manufacturers of construction machinery from achieving major sales in the Seventies. The trend towards quieter construction machines was also promoted by the "construction noise reports" voluntarily submitted by the Association of German Engineers (VDI) and designed to keep the general public and the trade informed about quieter construction machine models.

In 1968, the Federal Government issued a "Technical Instruction for Providing Protection against Noise" (TA Lärm) and this acquired great importance in the abatement of industrial noise. The Technical Instruction set out in detail the acoustic conditions on which the competent authorities could license the establishment and operation of noisy sites in any given area. The immission values named in the "TA Lärm" ranged from 3o dB(A) to 7o dB(A), and they were based on the varying noise-abatement requirements in the environs of the specific installations subject to authorization. The Technical Instruction "TA Lärm" soon became a general yardstick for measuring the acceptability of noise. During the past 15 years, TA Lärm and its demanding immission values have exercised a considerable influence on the containment of industrial noise: installations subject to authorization may only be "set up and operated" where it cannot endanger, substantially inconvenience or disturb the neighbourhood. And what about the cost? The administrative expense involved in the creation and application of TA Lärm can hardly be assessed in isolation - especially since the civil servants concerned have to be paid in any case. A more serious matter is the question as to the cost for industry, which repeatedly asserts that TA Lärm is too demanding and inimical to investment and therefore calls for a substantial relaxation of the requirements. However, industrialists have never submitted any precise data and TA Lärm has continued in force until the present day.

After approximately ten years of scientific and parliamentary preparations, the Aircraft Noise Act (5) came into force in 1971. On the one hand, the new Law defined the obligations of airport operators, aircraft operators and aircraft pilots to conduct their operations in a manner calculated to protect people against the effects of air traffic noise. On the other hand, the Law empowered the Federal Minister of the Interior to stipulate noise protection areas, each consisting of two protection zones, for about 45 civil and military airfields used by jet aircraft. The determining criterion was to consist in a future predictable level of noise exposure. In the noise protection areas, there apply graded restrictions on structural use depending on the degree of noise exposure: the owner of property has, to a specified extent, a claim against the airport operator to reimbursement of expenditure on structural sound insulation measures of a certain quality. During the last few years, about 5o ministerial orders have been enacted in amplification of the Aircraft Noise Act. So far, over 4o areas have been designated as noise protection areas.

Moreover, it is possible to cite precise figures on the cost of the measures adopted in connection with the Aircraft Noise Act. Up to the end of 1982, the Federal Defense Ministry had paid over DM 22o million to entitled local residents in respect of structural sound insulation measures for buildings in the noise protection areas of military airfields. As regards civil airfields (including those in West Berlin), a total of DM 157 million was disbursed for this purpose. The Federal Defense Ministry has spent over DM 18o million on the construction of antinoise hangars at military airfields. The voluntary resettlement of local residents at Pferdsfeld military airfield cost DM 8o million. The civil airports had paid over DM 15o million by mid-1981 on various measures relevant to noise control such as the purchase of particularly affected real estate or the payment of premia to airlines for using quieter aircraft. Altogether, this expenditure on protection against aircraft noise amounts to over DM 74o million.

It is difficult to quantify the cost of the Aircraft Noise Act for those citizens desirous of erecting residential premises on their land in the noise protection areas, but who are not allowed to do so at all in Zone 1 and only permitted to construct residences in Zone 2 if these meet the specific sound-insulation standards. In 1976/77, the Federal Environmental Agency put the additional expenditure on the prescribed anti-noise protection in Zone 2 at 2.2 to 2.5% of the actual construction costs - a percentage which has meanwhile probably decreased (6).

And what about the benefits conferred by all these measures? Today, thousands and thousands of local residents at airfields live in sound-insulated dwellings. Thanks to the anti-noise devices at military and civil airfields, the testing of engines no longer poses a problem for the neighbourhood. The noise protection areas inform the public about the location and intensity of noise exposure: moreover, they prevent any unrestrained erection of dwellings near to airfields and thus the emergence of new problematic situations.

New buildings contain the prescribed anti-noise facilities from the very beginning.

One of the priorities in the Federal Government's environmental policy

lies in the abatement of road traffic noise. The main concern is to ensure that motor vehicles become quieter. As a member of the European Community, the Federal Republic cannot reduce the generally accepted noise levels for motor vehicles of her own accord. For this reason, the Federal Government forwarded to the EEC Commission a memorandum (7) calling for a tightening of uniform threshold values throughout the European Community with effect from 1985 to between 75 and 80 dB(A), depending on the type of motor vehicle concerned. At the request of the EEC Commission, the committee of car manufacturers in the European Community (CCMC) expressed its views in July 1980 about the presumable economic and technical consequences (8). According to the CCMC's study, the purchase price for a passenger car with an emission value of 75 dB(A) instead of the presently applicable 80 dB(A) would rise by 4 to 10% whilst trucks and buses with 80 dB(A) instead of the presently applicable 82 to 88 dB(A) would cost 5 to 12% more - provided that the attainment of this figure was technically feasible.

In some cases the vehicle manufacturers Daimler-Benz, Magirus-Deutz and MAN have developed a whole series of different vehicles which meet the German target figures for 1985. The higher price compared with the louder versions will depend not only on the technical facilities required, but also on the size of the production run i.e. to a large extent on the demand. The Federal Government has refused to promote the sale of quieter vehicles by means of subsidies. However, it will cooperate with local bodies in introducing "operational advantages" for quieter vehicles pursuant to the Bad Reichenhall model. For example, if trucks cannot be used in general pursuant to anti-noise regulations, the quieter versions may be authorized as exceptions.

The Federal Government has commissioned a fairly large number of studies on road-traffic noise such as an examination of the acoustic significance of different tyres and road surfaces or the influence of a driver's behavior on noise levels. It was revealed that the difference between a driving style involving a low number of revolutions in the engine and a "sporty" driving style can substantially exceed 10 dB(A). As an as yet uncompleted study of trucks reveals, the driving style can result in a difference of between 5 and 6 dB(A). And what is the cost of such an impressive reduction in noise levels? Drivers must simply know of the facts and be prepared to behave appropriately. The motivating of drivers is helped by the fact that quieter driving usually signifies a saving of fuel during journeys. Hence, this represents one of the few cases where environmentally desirable behavior is directly rewarded in financial terms.

Even if the exacting German demands for a reduction in emission values by 1985 were to be realized it would take 8 to 10 years for the complete reducing impact to take effect because of the service life of motor vehicles. Furthermore, this reduction would by no means suffice to render additional protection measures for roads and buildings entirely superfluous. In recognition of the inadequacy of a reduction in emission values, the Federal Government presented the draft of a "Traffic Noise Control Act" in Parliament in 1977 and this was then enacted by the German Bundestag in amended form on 6.3.80 (9). Under this new Law, roads and railways must be planned in such a way as to avoid traffic noise immissions as much as possible. The enacted draft

Law provided for immission threshold-values for the construction or substantive modification of road or rail vehicles: depending on the needs of the given area for anti-noise protection, these limits range from 6o to 77 dB(A) by day and 5o and 67 dB(A) at night. If the noise level of the prospective volume of traffic exceeds the threshold value, then the responsible building authority (Federal Government, Land or local authority) must adopt protective measures along the given route by erecting an embankment, wall etc or else reimburse the proprietor for his or her expenditure on structural anti-noise devices such as insulated windows.

The draft Law also provided for a legal claim to noise abatement in existing streets and roads where the immission threshold value exceeds 7o to 75 dB(A) per day or 6o to 65 dB(A) per night, depending on the given district.

The draft Law did not gain the constitutionally required approval of the Bundesrat, the chamber representing the Länder governments. Although it did not become legally binding as a result of this, the draft Law is widely construed in administrative practice as a criterion for the requisite protection against noise. So for example 23o million DM were spent on noise protection at federal highways.

The benefit of these rules is clear to see. A salutary pressure is exercised on the planners of traffic routes to lay them out in a manner designed to afford protection against noise, since they otherwise face the threat of having to bear the cost of anti-noise measures. By the same token, private citizens either get a satisfactorily located traffic route and protection against noise or else at least the reimbursement of their expenditure on anti-noise facilities.

As the draft Law was being prepared, a vehement controversy arose about the concomitant costs. In 198o, the German Bundestag reckoned with the following yearly expenditure:

	DM millions
1. Federal Budget	
Anti-noise measures for future roads	21o
Anti-noise measures for future federal railroads	55
Anti-noise measures for existing roads	94
	359
2. Länder Budgets	
Anti-noise measures for future roads	36
Anti-noise measures for existing roads	38
	74

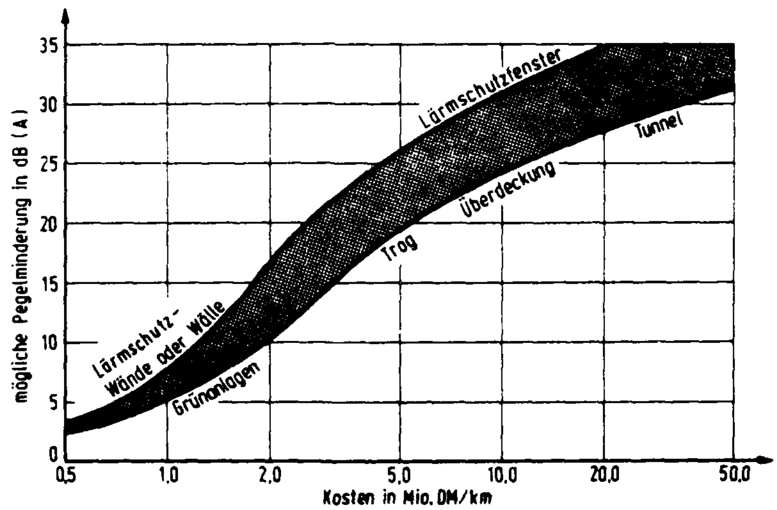
3. Local Authority Budgets

Anti-noise measures for future roads	44o
Anti-noise measures for future railroads	3
Anti-noise measures for existing roads	165
	6o8

Parliament proceeded on the basis of a yearly volume of federal investment in road-building of DM 4.5 billion and of local-authority investment of DM 6 billion.

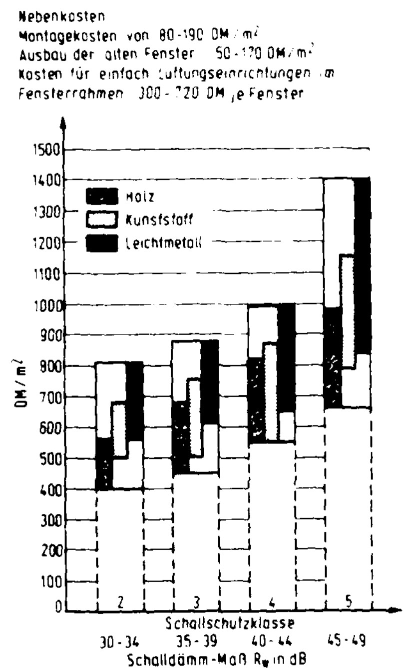
A more recent study (1o) on the cost of anti-noise measures for existing roads has computed a reduction of approximately 5o% in the estimated costs due to a more precise consideration of trucks' share of total traffic volume with a concomitantly big impact on costs. This example clearly demonstrates how problematic it can be to provide precise cost estimates for anti-noise measures on the basis of predicted noise exposure. However, such estimates may substantially influence political decisions on the threshold values. In the present case, the difference between the parliamentary assumptions and the latest findings amounts to no less than DM 5 billion!

The Federal Environmental Agency made a computation in 1981 to show how expensive and effective various anti-noise measures are along traffic routes:



UBA 1981	Größenordnung der Kosten für Schallschutzmaßnahmen an beiden Straßenseiten in Mio. DM/km. (nach Reinhold)	LA - Imm 030

Sound-proofed windows - depending on the chosen technical design and the sound insulation - together with incidental expenditure cost between DM 4oo and DM 1,4oo per square meter as shown in the illustration below:



UBA 1981	Kosten von Schallschutzfenstern 1979/80 einschl. Mwst., Planung u Montage, in DM/m²	LA-Imm 058

The benefits of noise research are difficult to quantify, although they are surely of great value in the long run. During the years 1976 - 8o, the public and private sectors spent about DM 15o million on noise research in the Federal Republic of Germany: the funds disbursed by the Ministry of the Interior trebled during this period and yielded major results, not least in research on noise impact. (11).

3. Considerable scientific efforts have been undertaken in the most recent times to develop reliable methods for ascertaining the cost/benefit ratio in noise control (12). This still involves great difficulties. Even the compilation of the probable costs inherent in an envisaged noise-abatement measure presents problems, particularly since negative effects of noise-control measures such as the impairment of the landscape by the erection of sound insulation walls or the diminution in the passage of information caused by the installation of insulated windows are difficult to quantify in money terms. A matter of even

greater difficulty consists in the correct assessment of the benefits of sound insulation measures in general. In this case, it does not suffice - as I have so far done in my paper - to refer to an improved situation expressed in dB(A). What we have to do is to indicate all the quantifiable consequences of the measure such as changes in the value of real estate, a reduction in the use of medicaments, the duration and nature of the hypertension avoided in this way, the reduced expenditure on recuperative travel etc. In addition, we have to take into consideration those peripheral effects of anti-noise measures which cannot be quantified or to an imperfect degree only: examples of this may be seen in the avoidance of reduced well-being, the lack of any interruptions in communication, and the preservation of one's accustomed residential habits.

Even though no satisfactory and universally valid method of analyzing the costs and benefits of noise control has hitherto emerged, it is nevertheless a great help to be able to use the available findings (e.g. for the political implementation of anti-noise measures).

4. Let me now point out the main issues:

- Noise control is a political task of great significance, especially in modern industrial societies.
- As the example of the Federal Republic of Germany shows, great efforts have been untertaken in recent years at considerable expense to diminish noise exposure.
- Although no satisfactory method of carrying out a cost/benefit analysis of noise control has yet been devised, useful and practicable beginnings in fact have been made in this direction. Parameters considered in the cost/benefit calculation that cannot (yet) be quantified must not be neglected. They should be introduced into the weighing process as unquantified but relevant factors.
- Noise control should start at the source. Here it is most effective. The first step often is relatively cheap, whereas the following steps are becoming increasingly more expensive.
- Measures at source cannot guarantee adequate noise control. The economically reasonable solution is a combination of various measures at source, during sound transmission, and at the place of exposure, adapted to the requirements of the individual case.
- There exists a particualarly favorable cost/benefit ratio in educating the people to handle their motor vehicles more carefully.

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CONCLUSIONS

The excellent reviews of this session on noise abatement planning and associated cost assessment together with some of the papers of the introductory session are clear evidence that a considerable technology base exists to tackle realistically and effectively this difficult problem. Certainly the agreements on the approaches taken, the predictions achieved and the remedies proposed by the various countries and international organizations far outweigh any shortcomings in methods and available data. The technical expertise to conduct such planning studies is available and continuing collaboration between administrators and acoustical experts should guarantee, as demonstrated in our presentations, that the results are obtained with the most appropriate and up-to-date methods.

Since many of the studies are either international from the start or have indirect international effects agreement on or standardization of the methods used is desirable and certainly adds to the acceptance of such studies and of the abatement programs based on them. The proposal we heard for the definition and units of noise exposure certainly adds to this important area and should be more widely used. The concept is to use linear units for cumulative noise exposure while retaining the familiar logarithmic decibel for sound pressure level as measured with the sound level meter. This proposal should appeal to both administrators and the public; it makes the values for alternative sound exposures and additions of sound exposures easier to comprehend by removing the logarithmic stumbling block and replacing it with conventional arithmetic quantities. The discussion brought out our limited knowledge of the non-occupational or leisure time noise exposure of individuals and populations and as a result the uncertainty in the total noise exposure of individuals. Since unfortunately in most countries occupational and non-occupational exposures are under different regulatory as well as research jurisdiction, it should probably be one of the most important research recommendations resulting from this session to emphasize the study of the noise exposure and of the resulting effects of leisure activities, at home, in neighborhoods, in urban and touristic areas. And to study the effects of the total

24-hour noise environment on individuals. Another research area has been mentioned several times at this session and at the congress in general: the impact of the technical and demographic changes which we predict in our planning studies, should be monitored by periodic surveys to verify predictions and the effectiveness of program execution. It is this area where we did not make the progress we had hoped for at the past congress five years ago. The final message we hear loud and clear is the need for dissemination of the predicted future changes, of the alternatives and of the potential costs. As in most similar areas, early planning and preventive measures are probably the most cost-effective, if not the only practically affordable approach to the desired future. To have support for such actions, it is of paramount importance to educate decision makers and the public of progress in the field and keep them informed about the outcome of our studies, of the options and related costs for influencing our environment of tomorrow.

Congress Summary

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BIOLOGICAL EFFECTS OF NOISE ON HEALTH-RESULTS AND INITIATIVES OF FOURTH INTERNATIONAL CONGRESS ON NOISE AS A PUBLIC HEALTH PROBLEM IN TORINO, ITALY, June 21 - 25, 1983

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Since our last Congress in Freiburg, 1978, the situations have changed and developed as a matter of course, in political, financial, and many other aspects. But the interest in questions concerning noise effects is still the same, the number of participants is kept constant (in Torino are even more attendees than in Freiburg) and the scientific investigations are as numerous as before. Concerning the quality of our results, which have been presented in these days to the public, we have to wait for and accept the assessment of those who need our data - either for politcal or administrative activities.

As already practiced in Freiburg, the Commission was eager to learn from political and administrative institutions their policies and current activities in the noise fields, in order to converge political-administrative needs and scientific interests or possibilities. The great international institutions (WHO, ILO and European Community) as well as some national authorities (Italy, Netherlands, USA) told us their wishes for their use, "We need simple but accurate prediction methods for noise effects". From a scientific standpoint, we have to modify this "contradictio in adjecto" into "as simple as even possible and as accurate as necessary". Such a simple method is the measurement of A-weighted noise; in the discussions of Team 1

(Noise-induced hearing loss), the participants raised the question if dB(A) is always justified: can it be used in noise areas with impulsive noise or in surroundings with low frequencies?

Other speakers pointed out, that occupational and public health aspects are complementary, that goverments in free market systems have to protect the noise exposed workers by legislative and administrative rules - regardless of the costs. "We are all responsible for the environment", and we want to know the risks and exposure limits for groups; though the individual is to be protected we are primarily interested in prediction of noise induced hazards for greater parts of the population. Other institutions told us that they want to have results from a comparable (but not identical) international work.

The fiscal austerities all over the world played an important part in the speeches and discussions of the introductory session. National and international bodies are concentrating their funding to a few projects; they set priorities which very often don't coincide with the imaginations of the scientists, especially with the ideas of the members of INT. It is encouraging to hear that in some countries priorities were fixed on projects that were recommended by the Commission in 1978:
1) Noise and health (with respect to sensitive groups);
2) Noise and cardiovascular risk;
3) Noise and social behaviour.

The research should be done by epidemiological and experimental means. Such decisions coincide with the requirements that were postulated as results of the Freiburg Congress:
1) Health effects of noise, expecially on cardiovascular system;
2) Effects of noise on sleep;
3) Impulse noise induced health effects.

In Freiburg it was stated that many problems in noise induced hearing loss were solved. There are still some detailed problems

scientists should deal with but the listed problems have high priority. One of the reasons of this is that the International Standardization Organization is depending on recommendations of INT from the results of noise effect research. ISO is standardizing measurement of noise with regard to noise reactions in human beings whereas the maximum permissible values are due to the national committees. So, international and interdisciplinary studies, characterize the work of INT.

As Chairman Tobias in his introductory and opening speech pointed out we are an association of multi-lingual groups of noise effect researchers, as he himself demonstrated when giving the first part of his speech in the Italian language. I was so much surprised that I asked myself if this congress would be an congress of surprises. Now, at the end of the congress I know, that it was not a congress of great steps, but of a great numbers of small steps, but brought us a great step forward, especially in such areas where I did not expect great progress. This might be useful for those who need our results.

One requirement of the Freiburg conclusion was the solution of the impulse effect problem. In the review of Team 1 it was stated that the equivalent energy rule was proved only for continuous, high level noise, whereas impulse did not follow exactly this rule. Therefore, additional suggestions of clarifying the concepts of impulse and impulse-exposure and to define impulse as $L_A$peak - L_{AX}-15 dB(A). By this and other criteria of impulse, background and mixed noise the impulse problem has come to a solution.

Results of laboratory and field studies showed that impulse noise is generally more detrimental to human beings than continuous noise. Examinations of stapedius reflex amplitude can explain this partially. This amplitude is not depending on energy but on time pattern, e.g. decisive is the energy that can reach the inner ear.

Besides the discussions of impulse noise load another problem was "noise susceptibility". Still unsolved is the question if young ears are more susceptible to noise or not;another problem is the question if high blood pressure is a prerogative of loss of hearing accuity or not. Longitudinal studies in this and other fields are urgent and necessary.

A great deal of papers and discussions were devoted to high frequency audiometry as a prediction method for a hearing loss. Animal experiments and toxicological tests (with Streptomycin) showed on early hearing loss in the very high frequencies above 8 kHz. Summarizing, it only seems to be clear that noise susceptibility tests by means of high frequency audiometry should be investigated further on.

Other communications dealt with socioeconomic factors as covariates of hearing loss, with biochemical parameters (Mg, increasing catecholamines etc.) influencing development of hearing loss, and with hearing conservation programs. The latter ones did not prove as effective as they were supposed so that a requirement for the future is to be seen in developing new "hearing conservation strategies".

During Team 1 session it was reported that within a 6 years longitudinal study at Fels College/USA boys had a better hearing than girls up to an age of fourteen years and then it turned. The question is raised whether it is a genetically or an environmentally conditioned factor. Due to financial restrictions, the study was ceased. ICBEN should try ro reactivate this study.

The last communication of Team 1 dealt with the restitution of the hearing after long-term noise load. In evaluating 10 research papers it was conluded that reactivation follows not a linear regression but shows an asymptotic approach after a restitution-plateau between 0.5hrs. and 4 hrs. I wonder,whether this

might lead - regarding individual variances - to susceptibility test?

Team 7 (Noise and Animals) gave a review of literature during the last five years. It showed the great difficulties to quantify the functional disturbances and the lasting, harmful effects, as well as the behaviour of wild living animals. So, a lack of information is still existing and most of the species cannot be assessed concerning the noise effects. Tests with caged animals are problematic and don't give, in most cases, valid data for the assessment of noise induced danger for wild living animals.

Observation of certain species, such as flamingos in Southern France, reindeer in Scandinavia and others, show us that most animals don't take notice of the noise but of the man. Therefore, Team 7 proposes to study:

1) individual groups of animals,
2) hearing sensitivity and environment,
3) combined stress reactions,
4) acute reactions and chronic changes, and
5) field vs. laboratory studies.

Team 4. In the team "Influence of Noise on Performance and Behaviour" several authors who contributed results during the last five years were present at the congress. Thus the contributions given dealt with

1) noise induced arousal reactions,
2) sensitivity tests,
3) relations between noise and internal speech
   a) in perceptual respects
   b) on memory
4) strategy-dependance of noise effects.

According to the reviewer the progress in these fields were greater than in the times between, i.e. before the two preceding congresses in Dubrovnik and Freiburg.

The reported investigations dealt with circadian rhythm and noise-induced arousal, with the inversed u-relation between performance and arousal, and with the differentiating of arousal in higher and lower functions. Concerning high meaningless vs. low meaningful noise the results showed stronger effects of the meaningful noise in mental tasks. On the other hand other factors than noise (e.g. unfamiliar speech) affect performance and memory more.

Other important results seem to be influenced by attitude, motivation, and attribuation. In addition to this, an anticipating noise exposure is influencing the aftereffects of noise, e.g. the thinking about noise is directing the aftereffects, not only behaviour but aftereffects-performance in the same way.

Order and location (for instance of numbers or words) in tests are differently influenced by noises. Normally the order is the more important factor but when location is emphasized noise is stronger in its effect. Besides this there are factors like appearance, attractiveness etc. that play a roll as well as numerous carry-over results affect later performance. It was found out that complex control processes govern task performance and that noise influences these control processes. Combined stimuli, noise and vibration, are influencing mental and trading performance differently; single vibration application and single noise application lead to clear, dose-depending results. But the combination vibration - 100 dB(A) and
vibration - 65 dB(A)
showed less effects in the louder combination. The contradictory results of some authors were explained by "side effects" like sex, arousal, daytime etc. A further result should be mentioned: a complex mental task showed subjects with coronary heart diseases more sensitive to noise than other healthy people.

In total we saw a lot of progress in this team concerning the activities and scientific results. On the other hand most

of the research was done experimentally in the laboratory. What now seems to be necessary is the combination of experimental laboratory and epidemiolgical field (practical) studies.

Research on extraaural effects of noise got essential impulses from the Freiburg Congress 1978. The literature review refered to publications dealing with various vegetative reactions and with biochemical effects of noise. Most of these studies were carried out under laboratory condition, but a greater number of them considered the Freiburg recommendations; they planned multivariate tests and evaluated them by adequate statistical methods. In some field studies multifactorial patterns were applied. This refers especially to investigations on effects of noise on critical groups which was another recommendation of the Freiburg congress.

Other publications dealt with mental health, neurovascular disorders, mortality rates and effects of noise on cardiovascular system. It should be mentioned, in addition, that one investigation was reported to the audiance showing that risk of noise can be assessed by use of multifactorial research design. This is only a first step but it should encourage the scientists of Team 3 to cooperate more.

Special problems and the scientific approach to them were shown when members of the team reported about the influence of noise on pregnant animals and pregnant women. Mice reacted less to noise than to other psychophysiological stress. Investigations in cardiac responses and in limb movements of human fetuses with noise of 76 dB (over 800 Hz) showed reactions which could not be classified as pathological findings but gave strength to the hypothesis of an elementary fetal auditory learning.

Investigation on noise and raised blood pressure were carried out as well under laboratory condition as with workers in noisy factories. Though there was a very small experimentally caused

and noise-induced blood pressure increase, the field study showed no significant effect. That is a typical situation for the differences between laboratory and field studies.

We should be eager to use precise definitions and speak only of physiological reactions which does not mean that these reactions are harmful. Only if it is proved that these reactions cause permanent functional disturbances with pathological values (e.g. more than 155 mmHg permanent systolic blood pressure) we are enabled to regard the noise influence as harmful.

Due to the fact that Team 8 - dealing with "Investigations of noise and other agents" - was not represented on the congress reports on infrasound and a review of last 5 years literature on interactive noise effects were given in the session of Team 3.

An investigation with longterm infrasound (20-3 Hz) from 70-125 dB did not produce nystagm or nausea. In combination with traffic noise, however, psychic tension, fitness and mood were changed. Infrasound was recognized as a non-specific stressor.

The review of interactive effects referred to combinations of noise with vibration, chemicals, smoking, thermal surroundings, physical work etc. and the reactions that were raised in the human body: biochemical changes, body temperature, cardiovascular changes, discomfort feelings, changes in work performance etc. Though some convincing results were reported. I got the impression that we don't know very much in these fields and that ICBEN should reinforce this team. Within the future congresses the specialists in these fields should be invited and requirements for research in this field should be set up as all other teams did.

The session of Team 5 (Noise disturbed sleep) was introduced by a review, as usual. Some topics of the five years scien-

tific work were pointed out. Concerning the old question: laboratory or home studies, it was stated that these could not be opposed to each other but they correspond to each other.

It is a fact that medical complaints and drug consumption are increasing in noisy environments during nights. Awakenings are underestimated up to now concerning the possible harmfulness. Cardiovascular reactions do not habituate. Some population groups are more sensitive to nightly noise, children show a retarded falling asleep in noisy environment.

The single communications dealt with various questions. So, EEG-data, performance on the next morning, and subjective assessment showed for those people living in noisy environments for more than 4 years <u>less</u> Delta-sleep which might be explained as an increasing sensitivity to noise. With the same people increasing age, bad health, and noise susceptibility tend to augment noise induced annoyance.

Intermittent noise is more disturbing than continuous noise for the sleeper who might be awakened already at peaks of 45 dB(A). In an other examination of physiological responses to traffic noise the findings suggest that there is existing a considerable adaptation to the continuous passage of vehicles during night. In a third paper dealing with this topic the results showed that the middle part of the night is the most sensitive part to noise; for airport noise a comparison of heart rates of the same people in 1976 and 1982 showed no influence though no habituation to the aircraft noise was seen.

In the center of the session stood the report of the Joint European Sleep Study which had begun shortly before the Freiburg congress. The results show during noisy nights less REM-sleep and more wakefulness; after the noisy nights the morning performances (reaction time tests) were reduced and the subjects reported deteriorated sleep quality. The correlation between mean heart rate/min. and heart rate variability is higher for high peak sound levels.

The authors gave as conclusions recommendations for the future international research collaboration not only in sleep fields. They have demonstrated an admirable joint work, nevertheless many questions remain open; I would have preferred to have heard something about the assessment of their results mainly if their findings could be regarded as harmful or purely as reactions within a normal range.

Other papers dealt with benzodiazepines which showed marked and dose-dependant effects on electrophysiological and cardiovascular responses to noise during night. Though the effects on sleep stages are also significant this is only a short-acting effect which is slowing down after the fourth night.

Discussing and summing up the results of the team session it has to be cleared in the future:

1) Is L_{eq} the useful and adequate measure?
2) Critical groups have to be investigated which are particulary sensitive to nightly occuring noise and
3) International cooperation has to be (re)inforced by adapting minimum requirements and methods of recording and evaluation.

In Team 2 (Noise and Communication) several reviews were presented: for English, French, German and Slavic literature. There is a lack of Eastern literature and of their findings and knowledge. ICBEN should in my mind activate contacts to Eastern scientists and institutions for a better exchange of scientific results and cooperation. The work in the other countries is still devoted to AI, STI, SPIN, and other evaluation systems.

The invited papers dealt with special topics. So we learned that a speech level meter is going to be developed, that STI is a good means for detecting speech intelligibility and

can be made applicable to interfering noise, reverberation and other types of disturbances, as well to normal hearing as to hearing impaired persons and to various laguages. Speech reception threshold for hearing impaired in different noise levels is dependant on age. Noise and reverberation have to be taken in account when assessing linguistically impaired listeners. Finally an analysis of warning signals in civil aviation was developed.

Discussing and summing up the contributions they resulted in expressing the need for applying the knowledge we have up to now. The relations between intelligibility and noise induced hearing loss should be studied as well as the relation between speech communication and jobs. Moreover the role of ear protectors in speech communication systems has to be detected.

All the results and findings of the other teams converge in a certain sense to the work of Team 6 (Community Response to Noise). The review gave not only a survey on the topics dealt with the last five years (like impulsive noise induced reactions, traffic noise influence etc.) but showed us the lacks, the missings of investigations in those fields that are getting more and more into attention: helicopter noise, combined noise and vibration load and its effects.

Several communications were devoted to aircraft noise and its effects. It was stated that the stimulus in aircraft noise is not a simple physical value but a combination of physical and human factors that modify perception and response making it unwanted, i.e. noise. The multiplications of the highest number, the peak exposures and the daytime are making their summary judgements of intermittent exposure; and at this factor 1/3 of the individual variance can be explained by the physical number and peak combination. By adding 3 of the human variables fear of crashes

harmful health effect
readiness to complain

we increase the explained variance of annoyance to 2/3.

In other papers it was reported of methodological examinations of noisiness functions and quantitative comparison procedures of different noise sources, on internationally coordinated and cooperated laboratory <u>and</u> field studies which enabled the author, - though only preliminary results are available - to conclude that the 5 dB penalty of ISO 1996 concerning impulse load is too moderate and should be between 9 and 13 dB according to their results.

Regarding road traffic noise, economic status and annoyance as well as sleep disturbances it was found in a field study that sleep disturbances began at L_{eq} = 53 dB(A), annoyance at L_{eq} = 63 dB(A) and changing of behaviour at L_{eq} = 66 dB(A).

Discussing and summarizing the sessions work they gave recommandations resulting in a closer cooperation and coordination between the single teams of ICBEN (esp. teams 1 and 5) and in promoting international co-work. Apart from this, suggestions were made to develop better methods for scaling and testing designs and for greater measurement precisions. Secondary analyses of former investigations should also be taken into account.

In the preceeding closing-session you just have heard the contributions to noise reductions and its costs, so I need not repeat their results. But you should allow me, finally, to give a personal comment on the whole congress. The results and initiatives of the Freiburg congress were successful concerning the last five years work of ICBEN. Some participants here in Torino told me that they were not so much contended with the practical value of a lot of results, others were impressed by the scientific work demonstrated here.

I personally regard ICBEN and the work of INT as a platform where science at its best an politics or/and administration can meet and exchange. The understanding for each other will increase, lastly we all serve the human being to live with dignity in an undestroyed and quiet environment. From this standpoint of view this congress was a progress and my personal thanks go to Prof. Rossi and his collaborators including the interpreter for his excellent organization and their work. Thank you.

CONCLUSIONS

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In my preface to the Congress, I promised that I would summarize the recommendations for the future that would arise from discussions held by the eight International Noise Teams. Let me keep that promise now.

Team 1: Noise-Induced Hearing Loss

Over the course of several meetings, the members of Team 1 created a list of recommendations for study during the next several years. I have paraphrased the Team's conclusions without, I hope, changing the content or the intent.

1. We must find an appropriate measure of exposure, especially for impact and impulse noise. The eight-hour L_{eq} is not correct for all exposures; but it will continue to be used, so correction factors need to be determined for a wide range of sounds. Animal studies, done by cooperation among laboratories, will help to shorten the time before we have some answers, but research workers first need to agree on which animal model to use, how to compute exposure, and how to

measure damage.

2. High-frequency audiometry has some attractive features, but conflicting evidence from cross-sectional studies demonstrates that only longitudinal studies of industrial workers and of appropriate controls are likely to lead to the validation of any test of susceptibility to noise-induced damage to the auditory system.

3. In addition, Team 1 believes several other problems are important and solvable. They include: (1) the development of normative data for high-frequency audiometry, (2) the study of the relation between otological abnormalities and susceptibility to noise-induced hearing loss, (3) determination of why some hearing protectors are more consistently effective than others, (4) the development of standard methods for evaluating nonlinear hearing protectors, and (5) the study of hearing aids for people with noise-induced hearing loss.

Team 2: Noise and Communication

Team 2, like Team 1 and all the other Teams, also met several times to discuss current problems and to consider directions for work during the near future. Here is their list of recommendations.

1. We need to encourage efforts to make our current knowledge more generally available, especially to people who design equipment and who design work- and living-spaces in which communication is important.

2. We need to learn more about the relation between decrements in hearing, including noise-induced hearing loss, and decrements in the ability to understand speech.

3. We need to make systematic definitions of the required degree of speech communication for various categories of work.

4. We need to quantify the effects on speech-intelligibility-in-noise of such things as non-native talkers, non-native listeners, and the use of synthetic speech.

<u>Team 3: Non-Auditory Physiological Effects Induced by Noise</u>

Here are the suggestions from Team 3.

1. Methodological inadequacies can be prevented if we develop a comprehensive model of sound as a physiological stressor and if we set up new studies that include multifactorial designs and complete statistical analyses.

2. We must concentrate on a few topics for the time being, and especially on cardiovascular morbidity.

3. We must increase international cooperation.

4. We must give a high priority to longitudinal epidemiological studies.

<u>Team 4: Influence of Noise on Performance and Behavior</u>

1. No single theory explains the effects of noise on behavior, so a multiple-theory research approach is recommended. A promising theoretical approach views noise as a psychological and physiological stressor. An amalgamation of theories into a metatheory should help research <u>producers</u> and research <u>users</u> to understand when each theoretical concept applies.

2. The meaning of a noise is probably based in individual differences among listeners as well as in the social and physical context in which the noise appears. The information content needs to be assessed.

3. Studies need to be designed to measure effects of noise on the underlying cognitive processes instead of just on the tasks being performed.

4. We need to look at the ways in which subjects develop stragegies for coping with short-term and long-term noise interference and at the psychological and physiological costs of these strategies.

5. Studies need to use real-world tasks, and laboratory work ought to be complemented by field studies. Both kinds of research should be broadened to include young and old subjects as well as those in the center of the age range.

Team 5: Noise-Disturbed Sleep

1. Work on traffic noise must be continued, including the expansion of field studies that look at the influence of changes in level.

2. Long-term health effects have to be determined.

3. We need to develop accurate predictors of sleep disturbance based in the acoustic characteristics of the noise: is the critical factor the noise level, the number or frequency of peaks, or some aspect of the sound that we have not yet considered?

4. We need to look for countermeasures. The single study of double windows must be replicated. The quieting of noise at the source has to be studied as does the smoothing out of peaks.

Team 6: Community Response to Noise

1. In order to avoid the expensive duplication of research and of facilities, joint and coordinated studies must

be encouraged. An extra benefit will be the combination of comparable data under a wider variety of conditions than could be managed in a single study.

2. Team 6 recommends that Team 6 and Team 1 (and maybe others) work together to develop a Total-Noise-Exposure Profile so that hearing loss can be studied in the context of work + nonwork exposures, and so that community noise can be studied that way too.

3. We need to increase the precision and appropriateness of our noise measurements and of our response measurements.

4. We have to use more sophisticated experimental designs and to enter into longitudinal studies, which can also help us to understand community reactions to noise-abatement procedures.

5. We should encourage investigators to contribute data to the data bank at the National Aeronautics and Space Administration's Langley Center in the United States and to use that data bank in planning new studies.

Team 7: Noise and Animals

1. We ought to include acousticians, ethologists, and psychologists on our research teams in order to improve the quality of the research.

2. We should include experimental controls for the mechanical and human intrusions and manipulations used in animal studies. For example, deafened animals can control for acoustic sensitivity and for noise effects in studies in which noise is combined with other stressors. Studies of marine organisms particularly need careful controls.

3. Interactive effects need to be studied further, not only as they have been, but also with regard to factors such as metabolism, germs and viruses, and biochemicals.

4. Because animal sensitivity is commonly not the same as ours, noise surveys must include both infra- and ultrasound frequencies.

Team 8: Effects of Interactions Between Noise and/or Other Physical and Chemical Agents

Only a little research has been done in this area recently, so the need is great.

1. Studies of vibration must continue as must the studies of interactions of noise and industrial chemicals.

2. We ought to start again looking seriously at studies of the interactive effects of common pharmaceutical agents and at the possibility of finding drugs that may inhibit the noxious effects of noise.

Ad Hoc Team on Noise Policy

At this Congress, in a session organized by Commission cochairman von Gierke, some of the more general issues facing all of the International Noise Teams were discussed. The group began by considering measurement problems, but as you will see, they expanded well beyond that important beginning.

1. Better noise indicators and assessment methods are certainly needed; in spite of that need, though, international agreement on the best measures currently available is critical to adequate planning and advocacy of noise reduction.

2. National and local noise-reduction plans must be followed up at least as often as every ten years with studies

designed to validate planning tools and to measure the effectiveness of actions and policies.

3. We must assess nd predict the impact of international, national, and local noise situations by looking at demographic and socioeconomic changes as well as at technical changes; planning and research may depend as much on the character of new leisure-time noises as on modifications in industrial technology.

4. Any improvement in the definition of the overall noise climate or in changes in the noise climate requires a better definition of the total exposure of individuals and populations during both work and leisure activities.

Conclusions

Every one of the Teams is concerned with accurate and appropriate measurement, with defining parameters, with adding longitudinal studies, with broader cooperation among laboratories, among Teams, and among nations, and with being able to predict the effects of a given kind and amount of noise on a given population.

This handful of recommendations can be expected to produce global effects--and I use the word "global" in both of its major meanings: first, the effects will be far-reaching and broad in scope, and second, they will be international in influence.

We all look forward to a productive and effective effort by scientists, by industrial workers and managers, and by government officials and agencies during the next few years so that in the Fifth Congress, we can show still more progress

toward the solution of our noise problems.

*　　　　*　　　　*

Acknowledgements

This Fourth International Congress on Noise as a Public Health Problem has had many purposes. We have given and heard and viewed and discussed research papers, and we have heard and discussed comments from national and international agencies that deal with noise. We have met with the various International Noise Teams. We have talked together and enjoyed each other's conversation and company. I'm happy to be able to thank every participant. And, on behalf of the Commission, I want to thank a few people a bit more specifically.

The younger participants in this Congress once again have proven themselves to be major contributors to our understanding of noise and of its effects. It is a pleasure to make my gratitude to them public.

Several people deserve special mention. They include Professor Rossi's several assistants, all of whom were helpful and invaluable. Among them, Lucy Ottley was particularly important and earned our respect and appreciation for her work with the officers of the Commission.

Marco Vigone worked behind the scenes for many months to help to create this Congress. He too merits our sincere gratitude.

Mrs. Rossi made major contributions, particularly in her work with the accompanying members. She has our warmest

regards.

One person above all others needs to be recognized: he is the Father of the Congress. Giovanni Rossi has spent several years in planning and developing this meeting, and without him it would not have been such a memorable success. Thank you Professor Rossi.

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FAREWELL SPEECH

G. Rossi

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Dear friends and colleagues, ladies and gentlemen,

Our congress is over. It is time for each of us to think over what has been achieved so that a balance can be struck - of a provisional nature at first, perhaps - in the expectation that time will transform these first impressions into more fully considered convictions.

At present, therefore, I wish only to dwell not so much on an overall evaluation of the scientific results that emerge from the papers and the ensuing discussions, as on the significance this Congress enjoys on both the national and the international level.

When I undertook to arrange this congress at Freiburg in 1978, public opinion in Italy was beginning to devote to the question of noise pollution that measure of attention the very vastness of the problem deserves. For a variety of reasons it would be out of place to examine here, this took place later than in other industrialised countries. Nevertheless, the massive participation of persons from all over Italy directly concerned with the solution of the scientific, theoretical

and practical questions associated with noise pollution enables me to assert that even Italy is now taking notice of the problems it raises. This observation is one that I wish to stress, since it is a source of particular personal satisfaction.

On the international plane, there has emerged in all its broad significance the importance of interdisciplinary cooperation and research conducted by workers from different countries.

Particular reference may be made to what the European Economic Community has been planning and putting into effect for several years. I look forward to the possibility that this example may be quickly extended to initiatives that may also be of interest to the developing countries, for whom the approach of an industrialised society will pose the necessity of dealing with the question of noise pollution.

Before bringing these brief farewell remarks to a close, I should like to address a common and sincere word of thanks to both the moderators, speakers, and attendees and to all those who in their several ways have made it possible to stage this Congress. Our gratitude is particularly directed to the firms that have taken part in the display of scientific apparatus and equipment, my assistants at the Audiology Department of the University of Turin, and the secretarial staff of the C.S.A.O., for their long, silent but decisive collaboration.

There will certainly have been things that went wrong or were overlooked - please accept my apologies for them. Yet at this moment I draw consolation from the fact that we can assert that the engagement or our goodwill has been both complete and total.

It is not yet possible to foresee what fruits will spring from this congress, nor the practical benefits our society may draw from the technical and scientific contribution made by the date we have been presented. When a final balance can be drawn up, we shall certainly realize that the days spent in this city, which has offered you a heartfelt welcome, while they may not have provided definitive solutions

for many of the problems associated with noise pollution, will indeed have enabled the foundations for further progress to be laid.

If this is the case, and I am sure that it will be so, then we shall have every right to feel proud and satisfied. The path before us is long, difficult, and strewn with obstacles. Yet this itself should serve to strengthen in each of us the will to persevere in our undertaking to pave the way for a tomorrow which we hope to see our wish for progress realized, without conflict, but indeed in harmony with an increasing betterment of the conditions in which we live.

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